IV. *Experiments and Observations on the various Alloys, on the specific Gravity, and on the comparative Wear of Gold. Being the Substance of a Report made to the Right Honourable the Lords of the Committee of Privy Council, appointed to take into Consideration the State of the Coins of this Kingdom, and the present Establishment and Constitution of his Majesty's Mint. By* Charles Hatchett, *Esq. F. R. S.*

Read January 13, 1803.

LIST *of the* COMMITTEE *appointed on the* 10*th of February,* 1798, *to take into Consideration the State of the Coins of this Kingdom.*

EARL OF LIVERPOOL, PRESIDENT.
THE LORD HIGH CHANCELLOR OF GREAT BRITAIN.
THE LORD PRESIDENT OF THE COUNCIL.
THE LORD PRIVY SEAL.
HIS MAJESTY'S PRINCIPAL SECRETARIES OF STATE.
THE MASTER GENERAL OF THE ORDNANCE.
THE FIRST LORD COMMISSIONER OF THE ADMIRALTY.
THE FIRST LORD COMMISSIONER OF HIS MAJESTY'S TREASURY, AND CHANCELLOR OF THE EXCHEQUER.
HIS MAJESTY'S SECRETARY AT WAR.
HIS GRACE THE DUKE OF MONTROSE.
THE LORD CHIEF JUSTICE OF HIS MAJESTY'S COURT OF KING'S BENCH.

INTRODUCTION.

THE Lords of the Committee of his Majesty's most honourable Privy Council, appointed by his Majesty, on the 10th of February, 1798, to take into consideration the state of the coins of this kingdom, having among other circumstances remarked the considerable loss which the gold coin appeared to have sustained by wear within certain periods, and being desirous to ascertain whether this loss was occasioned by any defect, either in the quality of the standard gold or in the figure or impression of the coins, were pleased to request that HENRY CAVENDISH, Esq. F. R. S. and myself would examine, by such experiments as should be deemed requisite, whether any of these defects really existed.

Two questions were to be principally decided,

1st. Whether very soft and ductile gold, or gold made as hard as is compatible with the process of coining, suffers the

most by wear, under the various circumstances of friction to which coin is subjected in the course of circulation?

2dly. Whether coin with a flat, smooth, and broad surface, wears less than coin which has certain protuberant parts raised above the ground or general level of the pieces?

Concerning the first question, opinions were various, and the most intelligent persons were uncertain whether very soft or hard gold was to be preferred; and, in respect to the second question it must be observed, that although the prevalent opinion was in favour of flat and smooth surfaces, yet, as the fact had never been fully and satisfactorily determined, this opportunity was embraced, in order that every doubt might be removed.

The great value of the material, had hitherto prevented private individuals from ascertaining these facts by experiment; and, as a public concern, this subject of investigation, although so important to political economy and to science, does not appear to have been noticed by any European government, until the Right Honourable and enlightened Members of the abovementioned Committee proposed the inquiry, and furnished the requisite means for making the experiments.*

At the request of Mr. CAVENDISH, I have written the following account; but I should be highly unjust and ungrateful to that gentleman, did I not here publicly acknowledge how great a portion truly belongs to him, of any merit which these experiments may be found to possess: for, at all times, I was favoured with his valuable advice; and the machines to produce friction, as well as the dies, were entirely contrived by himself. At the

* These experiments were begun in the latter end of 1798, and were completed in April, 1801.

same time, I wish it to be understood, that I alone am to be considered as responsible for any inaccuracies of the experiments.

Lastly, before I proceed, I must take this opportunity to acknowledge my obligations to JAMES MORRISON, Esq. the Deputy Master of the Mint, to Mr. JAMES MORRISON, his son, to ROBERT BINGLEY, Esq. his Majesty's Assay Master, and to Messrs. ATKINSON and NICHOLL, of the Corporation of Moneyers, for the ready assistance and polite attention which I received from those gentlemen, during the long series of experiments made at the Mint.

SECTION I.

ON THE VARIOUS ALLOYS OF GOLD.

The wear of coin is an effect produced by mechanical causes, subject to be modified by certain physical properties, such as ductility and hardness, which vary in degree, according to the chemical effects produced by different metallic substances, when employed in certain proportions as alloys. From these considerations, it appears proper,

First, to examine the effects which the various metals produce upon gold, when combined with it in given proportions, beginning with $\frac{1}{12}$, which is the standard proportion of alloy, and in certain cases gradually decreasing to $\frac{1}{4}$ of a grain in the ounce Troy, or $\frac{1}{1920}$ part of the mass.

Secondly, to examine the specific gravity of gold differently alloyed, and the causes of certain variations to which it is liable.

And, thirdly, to ascertain the effects of friction variously modified.

GOLD ALLOYED WITH ARSENIC.

Experiment I.

Eleven ounces one pennyweight and three grains (= 5307 grs.) of gold, 23 carats $3\frac{1}{2}$ grs. fine, being completely melted, eighteen pennyweights and twenty-one grains (= 453 grs.) of pure metallic arsenic were added, and the whole being rapidly stirred, was quickly poured into a greased mould of iron.

The bar was of the colour of fine gold, and, although brittle, yet it bent in some measure before it broke. It weighed eleven ounces one pennyweight and nine grains; so that, of 18 dts. 21 grs. of arsenic, only six grains remained in combination with the gold; consequently, 18 dts. 15 grs. had been volatilized.

Experiment II.

As the fine gold, in the foregoing experiment, retained so very small a portion of the arsenic, it appeared possible that copper might assist to fix that volatile substance.

To eighteen pennyweights and ten grains of the fine gold in fusion, nineteen grains of pure copper were added, being half the weight of the standard proportion of alloy.

When the copper was perfectly melted, and, by stirring, had been well incorporated with the gold, the crucible was removed, and at that moment nineteen grains of arsenic were added, and being quickly stirred, the metal was immediately poured into a mould.

The time which elapsed from the raising of the crucible to the pouring of the metal, was rather less than one minute; but, upon weighing the ingot, it appeared that the whole of the 19 grains of arsenic had been volatilized; and this was

corroborated by the perfect ductility which the gold was found to possess.

In this experiment, the whole of the arsenic was separated; and we may conclude, that it is always difficult to combine arsenic with gold by mere addition in open vessels, and that when to a small quantity of gold in fusion, a small quantity of arsenic is added, it is immediately dissipated by the violence of the heat; but, if large quantities are employed, and the metal is poured as soon as possible after the addition of the arsenic, then, according to circumstances, a small portion may remain combined with the gold.

It is well known that arsenic may be easily combined with gold and other metals, when in fusion, by employing a mixture of oxide of arsenic and black flux, and performing the operation in close vessels; but the following experiment will prove, that arsenic may at all times be combined with gold, provided the latter, when it loses its heat and congeals, is surrounded by arsenical vapour.

Experiment III.

480 grains of fine gold were put into a four-inch crucible, which was then placed within a large one that measured about 12 inches. At the bottom of this last, and on the outside of the small crucible, one ounce of metallic arsenic was placed, and another large crucible was then closely luted, with its mouth inverted upon that of the lower one.

The whole was exposed to a strong heat in a wind-furnace, during two hours, after which, the vessels were suffered gradually to become cold. Upon removing the upper crucible, which formed the dome, some white oxide of arsenic was found adhering to the inverted bottom of it.

2dly. The remainder of the metallic arsenic coated the bottom of the inferior large crucible.

3dly. On the sides of the upper crucible or dome were several small globules of gold. And,

4thly. The button of gold in the small crucible, although unchanged in external appearance, was found to be extremely brittle, and, when broken, the fracture appeared of a coarse grain, and of a gray colour.

The button weighed 481,5 grs. so that, exclusive of the gold which had been volatilized, there was an increase of the original weight, amounting to 1,5 gr.

When arsenic is by any means combined with gold, it is not easy to separate it totally by mere heat; for, although this button was twice kept in strong fusion, during one hour each time, in an open crucible, it still retained some arsenic, and continued to be brittle.

From this last experiment it is evident, that a considerable degree of affinity prevails between gold and arsenic; but, as the latter is immediately volatilized at the instant of contact with melted gold, it cannot easily be combined with it when open vessels are employed, and when the arsenic is simply added to the gold in fusion, while so great a degree of heat is continued.

This volatility of arsenic is, on the contrary, in favour of the combination when the operation is performed in close vessels; for, as arsenic is reduced to a state of vapour by heat much inferior to that which is requisite to the fusion of gold, and as this vapour remains included during the melting and cooling of the gold, it necessarily follows, that the gold is cooled, and becomes solid, while immersed in the arsenical atmosphere, so that the state of the gold, the extreme division of the arsenic,

and the gradual cooling of the vessels, in every way promote the union of the two metals.

ADDITIONAL EXPERIMENTS UPON GOLD AND ARSENIC.

Since the above experiments were written, I was induced to examine what effects would be produced by arsenic, in the state of vapour, upon red-hot plates of standard gold, the alloy of which was copper.

With the assistance of Mr. BINGLEY, I therefore made the following experiments.

I.

Two six-inch crucibles were ground so as to fit close when the mouth of one was inverted upon the other. Within the upper crucible or dome, a plate of the standard gold, which was $2\frac{1}{2}$ inches long, $1\frac{1}{2}$ broad, and $\frac{1}{30}$ thick, and slightly bent, was suspended by a strong iron wire; and one ounce of metallic arsenic was put into the lower crucible. The vessels were then closely luted, and were placed in an open fire, so that they became of a full red heat; they were kept in this state about 12 or 15 minutes, after which, they were removed from the fire, and when cold were opened.

I then found, that although the heat had been so very much inferior to that which is requisite to cause the fusion of gold, yet, in the present case, some very extraordinary effects had been produced; for the arsenic, which had been resolved into vapour, had acted upon the red hot plate of gold, and had combined with every part of its surface; but the combination so formed, being extremely fusible, had immediately separated from the remaining plate of metal, and had fallen into the lower crucible, where it had formed an ingot or button. This ingot

was internally of a gray colour,* and was extremely brittle; but the plate from which the portion of gold had been separated, remained perfectly ductile, and did not retain any of the arsenic; for, although it was superficially discoloured, it was unchanged in every other respect, excepting that the sharpness of its edges was destroyed, and the thickness was reduced from $\frac{1}{30}$ of an inch to that of common writing paper.

The effects produced by the arsenic, in this experiment, were very remarkable; for the plate was as uniformly and evenly reduced in its thickness as if it had been planed; and, while the portion which had dropped from it was combined with a very large quantity of arsenic, the remaining part of the plate appeared to have preserved the whole of its original ductility and purity.

These singular effects took place, as I have already observed, in so short a time as 12 or 15 minutes; but I wished to ascertain whether the same would not happen, more or less, within a smaller period, and under circumstances not so favourable to the union of arsenic with gold.

II.

Two six-inch crucibles were fitted, and inverted in the manner already described, and a plate of the standard gold, similar in size and quality to that which had been employed in the first experiment, was in like manner suspended within the upper crucible or dome.

A semicircular piece was cut out of the lip of this crucible, so that, when inverted and luted upon the lower vessel, there was an aperture of about $1\frac{1}{2}$ inch in diameter, which was

* The external colour was like that of fine gold, in consequence of the arsenic having been volatilized from the surface of the ingot, by the heat of the lower crucible.

loosely stopped with a piece of charcoal, and the crucibles, being firmly luted, were as before placed in an open fire.

When the vessels appeared of a full red heat, they were taken out, and, being placed upon the pavement of the laboratory, about half an ounce of metallic arsenic was quickly introduced through the aperture that has been mentioned, which was again closed, although very imperfectly, by a piece of charcoal. The arsenic immediately began to produce flame and fumes, which partially escaped through the opening; in about five minutes, the crucibles ceased to appear red-hot, and the greater part of the arsenic was dissipated.

Upon separating the crucibles, the plate of gold was found entire, but it was much discoloured; and the portion of gold which had combined with the arsenic, had trickled to the edges of the plate, where it became accumulated, and would soon have dropped into the lower crucible, had it not been for the short duration of the heat.

The plates of gold which were employed in the two experiments, had been annealed, and were remarkably ductile; and it has already been observed, that the part of the plate which remained after the first experiment, completely retained its original ductility; but the plate which had been employed in the second experiment, although not brittle, was become less flexible. The cause of this difference was very apparent; for, in the first experiment, the whole of the gold combined with arsenic had, by the continuance of the heat, been enabled to flow from the remaining part of the plate of standard gold, which, although thus reduced in size, retained none of the arsenic.

In the second experiment, on the contrary, the heat ceased,

almost as soon as a portion of the arsenic had united with the gold; and the whole surface of the plate, therefore, remained thinly coated with arsenicated gold, by which, a certain degree of rigidity was produced.

These experiments prove, that arsenic, in the state of vapour, will readily combine with gold, even when the latter is only raised to a common red heat. But the whole substance of the gold is not, in this case, immediately and completely pervaded by the arsenic; for it appears, that the combination of these two metals, being extremely fusible, immediately flows, and is separated from the remaining part of the mass of gold, provided that the original degree of heat be not very speedily checked; but, when this happens, the mass or plate of gold remains coated with the arsenicated compound.

The effects which (according to these experiments) metallic arsenic appears to produce upon gold in a red heat, may in a great measure be compared to those which are observed when sulphur, or phosphorus, is combined with various metallic substances.

GOLD ALLOYED WITH ANTIMONY.

Experiment I.

To eleven ounces one pennyweight and three grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, in perfect fusion, eighteen pennyweights and twenty-one grains of pure antimony were added, and, being well mixed, the whole was poured into a mould of iron.

This mixture had in some degree acted upon the surface of the mould; for it was with difficulty that the bar could be

removed; and, when this was effected, the internal surface of the mould appeared corroded in some parts, and, as it were, inlaid by the mixed metal.

Upon weighing the bar, it was found that only 15 pennyweights of the antimony remained combined with the gold; so that three pennyweights and twenty-one grains had been dissipated.

This metal was of a dull pale colour, not very unlike tutenague; it was excessively brittle, and in the fracture appeared of an ash colour, with a fine close grain, somewhat resembling that of porcelain.

Experiment II.

To eighteen pennyweights and ten grains of the fine gold, in fusion, nineteen grains of copper were added, which being melted and well mixed, nineteen grains of antimony were also added; after which, the metal was poured into a mould.

The external colour of the button was like gold made standard by copper; it was very brittle, and, in the colour and grain of the fracture, resembled the result of the preceding experiment.

Experiment III.

Eighteen pennyweights and ten grains of the fine gold, were alloyed with one pennyweight and six grains of copper, and afterwards eight grains of antimony were added, to complete the standard proportion of alloy; the mixture was then poured, as expeditiously as possible, into a mould.

The ingot resembled that of the former experiment, in every particular, excepting that the grain of the fracture was more coarse, although it was still devoid of metallic lustre.

Experiment IV.

Eighteen pennyweights and ten grains of the fine gold, were alloyed with one pennyweight and ten grains of copper, and, when in perfect fusion, four grains of antimony were added.

The external colour of the ingot was like that of *Experiments* II. and III. It was very brittle, and the grain of the fracture was similar to *Exper.* III. excepting that it shewed a small degree of metallic lustre.

Experiment V.

To one ounce sixteen pennyweights and twenty grains of the fine gold, alloyed with three pennyweights and three grains of copper, one grain of antimony was added, and the mixture was treated as before.

The antimony, in this mass, was in the proportion of only half a grain in each ounce; but the ingot was completely brittle, and the fracture still shewed a close grain, although the metallic lustre now began to be more apparent.

Experiment VI.

The two ounces of the metal formed by the preceding experiment, were added to two ounces of gold made standard by fine copper.

The proportion of antimony, in this experiment, could at most be estimated only at $\frac{1}{4}$ of a grain in the ounce; but, as it may be supposed that, by the repeated meltings, some of the antimony had been volatilized, it probably was in a less proportion.

The ingot formed by this experiment was, in colour, and in other properties, very like that of *Exper.* V. It was, however, in a

slight degree less brittle, as it did not so immediately break under the hammer.

The foregoing experiments prove, that $\frac{1}{4}$ of a grain of antimony in the ounce, or $\frac{1}{1920}$ part of the mass, can destroy the ductility of gold.

The following experiments were made to ascertain the effects of the vapour or fumes of antimony upon gold, when close and when open vessels were employed.

Experiment VII.

480 grains of fine gold were exposed, in close vessels, to the fumes of about 480 grains of antimony, under circumstances similar to those described in the third experiment upon arsenic.

When the crucibles were unluted, the chief part of the antimony was found, unchanged, at the bottom of the inferior large crucible.

The button of gold in the small crucible was not altered in the external colour, but proved to be extremely brittle, for it immediately split under the hammer, and exhibited a close grained earthy fracture, of an ash colour.

After the experiment, the button weighed 483,9 grs.; so that it had acquired 3,9 grs. of antimony.

Experiment VIII.

A small four-inch crucible, containing 480 grains of fine gold, was placed within another, of 12 inches; and four ounces of antimony were put into the large outer crucible, as soon as the gold appeared to be perfectly melted.

When half an hour had elapsed, the small crucible was

removed, and the gold was poured into a mould. The button was externally of a dull brownish colour, and was very brittle.

From the two last experiments, it may be inferred, that gold, when melted in close, and even in open vessels, attracts and combines with antimony in the state of vapour.*

GOLD ALLOYED WITH ZINC.

Experiment I.

Eleven ounces one pennyweight and three grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, were melted, after which, eighteen pennyweights and twenty-one grains of zinc were added, and, being quickly stirred, the whole was poured into a mould of iron.

Upon the addition of the zinc, a bright flame immediately arose; and, although as little time as possible was lost, yet, upon weighing the bar, it appeared, that in this short period, five pennyweights and twenty-one grains of zinc had been volatilized, and that only thirteen pennyweights remained combined with the gold.

The bar was of a pale greenish yellow, like brass, and was totally devoid of ductility.

Experiment II.

Eighteen pennyweights and ten grains of the fine gold, were alloyed with 19 grains of copper, to which, when completely melted, 19 grains of zinc were added, and, being expeditiously mixed, the metal was poured into a mould.

The external colour of the ingot was pale yellow; it was

* It has been proved, that arsenic will not combine readily with gold in open vessels; but the reverse was observed when antimony, zinc, and some other metals, were reduced to vapour in the vicinity of melted gold. This effect appears to depend on the relative affinities of the different metals with gold and with caloric.

very brittle, and, like the former bar, exhibited a coarse grain in the fracture.

Experiment III.

Eighteen pennyweights and ten grains of the fine gold, were alloyed with one pennyweight and six grains of copper, and, when in fusion, eight grains of zinc were added.

This experiment was conducted as quickly as possible; but nevertheless, upon weighing the ingot, it appeared that the whole of the zinc had been volatilized; and this was farther proved, by the colour, and by the perfect ductility of the metal.

Experiment IV.

To eleven ounces one pennyweight and three grains of the fine gold, in fusion, eighteen pennyweights and twenty-one grains of fine brass wire were added, and mixed as before.

The external and internal colour was of a fine pale yellow; but the metal was very brittle, and the grain of the fracture was coarse.

Experiment V.

To eighteen pennyweights and ten grains of gold, alloyed with 19 grains of copper, in fusion, were added 19 grains of fine brass.

This ingot did not, in general properties, differ from the former.

The following experiment was made, to ascertain the effects of zinc upon gold, when the two metals were melted in open vessels, near each other, without being in absolute contact.

Experiment VI.

One ounce of fine gold was melted in a four-inch crucible, which had been previously placed within another, of 12 inches.

As soon as the gold was in complete fusion, about four ounces of zinc were put into the large crucible.

A considerable flame, accompanied by a large quantity of white oxide of zinc, immediately arose, and part of the oxide adhered to the interior of the large crucible.

Within half an hour, the crucible containing the gold was removed, and was suffered to cool.

Upon examining the button, it appeared, that a portion of the volatilized zinc was combined with the gold; for the surface was dull, and of a Spanish snuff colour; moreover, it proved to be very brittle, similar to the former results.

From these experiments, it is evident, that zinc is highly injurious to the ductility of gold; that a portion of it is easily separated from gold by heat; that, when a large quantity of gold is alloyed with the standard proportion of zinc, only part of the latter is speedily volatilized, but, when small quantities are treated, the whole of the zinc becomes separated, and the gold remains pure; that, if zinc is previously combined with copper in the state of brass, it is not so easily separated by heat, when added to melted gold; and, lastly, that gold in fusion absorbs and retains a portion of zinc, when exposed to the latter metal in a volatilized state, even in open vessels.

GOLD ALLOYED WITH COBALT.

Experiment I.

The effects produced by cobalt upon gold, do not appear to have been hitherto investigated; for this reason, the following experiments were made.

To eighteen pennyweights and ten grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, when in fusion, one pennyweight and fourteen

grains of pure metallic cobalt were added, and, being well melted and mixed, the whole was poured into a dry cupel.

The external colour of this metal was a dull yellow; it was very brittle, and the fracture appeared of a pale yellow, with an earthy grain.

Experiment II.

To eighteen pennyweights and ten grains of the fine gold, alloyed with 19 grains of pure copper, were added 19 grains of metallic cobalt, which being perfectly melted and mixed, the whole was treated as before.

The metallic button, externally, appeared of a pale yellow, slightly tinged with gray; it was brittle, and shewed a fine-grained earthy fracture.

Experiment III.

Eighteen pennyweights and ten grains of the fine gold, alloyed with one pennyweight and six grains of copper, being melted, eight grains of cobalt were added, and mixed.

The colour of this ingot was like that of the former, but the yellow colour was rather deeper. It soon broke under the hammer, and the fracture was still of a fine grain, inclining to an earthy appearance.

Experiment IV.

To eighteen pennyweights and ten grains of gold, alloyed with one pennyweight and ten grains of copper, four grains of cobalt were added. The colour of this metal resembled that of gold made standard by copper, excepting that it was rather paler. This ingot was but slightly brittle.

As the last metal began to be ductile, the experiments with cobalt were not continued.

GOLD ALLOYED WITH NICKEL.

Experiment I.

Eighteen pennyweights and ten grains of the fine gold, were alloyed with one pennyweight and fourteen grains of pure metallic nickel, and the whole was then poured into a cupel.

This button was of the colour of fine brass; it immediately broke under the hammer, with a coarse-grained earthy fracture.

Experiment II.

Eighteen pennyweights and ten grains of fine gold, being alloyed with 19 grains of copper, were afterwards melted, and mixed with 19 grains of pure nickel. The external colour of this metal resembled gold made standard by copper, but was paler in a slight degree. It was brittle, and shewed a fine-grained fracture, of an earthy appearance.

Experiment III.

Eighteen pennyweights of the fine gold, alloyed with one pennyweight and six grains of copper, being melted, eight grains of nickel were added, and mixed as before. The colour of the ingot was like that of the former experiment, and the metal proved to be only slightly brittle.

Experiment IV.

To eighteen pennyweights and ten grains of fine gold, alloyed with one pennyweight and ten grains of copper, when in fusion, were added four grains of nickel. The colour of this button was like that of gold made standard by copper, and, under the hammer and rollers, it was found to be perfectly ductile.

From these and the following experiments it appears, that, of all those which have been improperly called semimetals, nickel is that which is the least injurious to the colour and ductility of gold.

GOLD ALLOYED WITH MANGANESE.

From what is at present known, it does not appear that this combination has till now been made.

Experiment I.

480 grains of gold, 23 car. $3\frac{3}{4}$ grs. fine, being put into a crucible, were covered with about half an ounce of pure black oxide of manganese. The crucible was then exposed to a strong heat, in a wind furnace, during one hour and an half; but not any alteration was thus produced in the properties of the gold.

Experiment II.

A quantity of olive-oil was several times mixed, and burned, with some of the oxide of manganese, after which, about one ounce of the oxide was put into a crucible lined with charcoal.

A piece of fine gold, weighing one ounce, was then placed in the middle of the oxide, over which a stopper of charcoal was put, and the whole was closed by a cover, firmly luted.

After a strong heat of one hour and an half, the crucible was removed, and, when cold, was broken.

The manganese, in which the gold had been embedded, still remained in a pulverulent state, but, from black, was changed to a dark green.

The button of gold at the bottom of the crucible was of a pale colour; it soon broke under the hammer, and shewed a spongy coarse-grained fracture.

Experiment III.

From the effects last mentioned, it was evident that manganese could be thus combined with gold; the experiment was therefore repeated, and the heat was continued during three hours, at the end of which time the crucible began to be melted.*

Upon breaking the crucible, which had been suffered to cool in the furnace, the manganese was found to be pulverulent in some parts, and indurated in others. There were not any metallic globules to be seen; and the colour varied from dark to pale grass green.

The button of gold at the bottom of the crucible was uniform, and externally of a pale yellowish gray colour, with a considerable lustre, almost equal to that of polished steel.

On that part of the button which had been next to the bottom of the crucible, were some specks of pale green enamel. The metal possessed a small degree of ductility, although extremely hard, for, when placed upon an anvil, being repeatedly struck with a heavy hammer, the button was in some measure flattened, before it could be broken.

The fracture was coarse, very spongy, and of a reddish gray colour; and many cavities, in the interior of the mass, were filled with the dark green coloured manganese.

It has been generally observed, that metals, when combined with manganese, are liable to a speedy change and diminution of lustre, colour, &c. when exposed to the air; but gold alloyed

* This reduction and union of manganese with gold, seems to have been effected by the double affinities between oxygen, carbon, gold, and manganese; and there is every reason to believe, that the above method may be advantageously employed, to form the alloys of the refractory metals with those of easy reduction and fusibility.

in the manner abovementioned, did not suffer (even when several months had elapsed) any perceptible alteration.

Mr. BINGLEY, who was always obligingly ready to assist in these experiments, at my request, examined the habits of this combination of manganese with gold, by the usual process of assaying. He found that the manganese was completely metallized, and combined with the gold, but not in an exactly equal proportion throughout the mass; for, in one part the manganese amounted to $\frac{1}{8}$, and in another to $\frac{1}{9}$.

The gold defends the manganese, in the metallic state, from the action of those acids which usually dissolve it.

When the mixed metal is exposed to a great heat, with free access of air, it loses its metallic lustre, and is covered with a dark brown oxide.

24 carats of the metal, which had been exposed to a considerable heat under a muffle, acquired $\frac{1}{19}$ of its weight.

Another time, under similar circumstances, it acquired $\frac{1}{16}$ of its original weight; but this proportion of oxygen disposed it to vitrify, and the mass was fixed to the cupel by a dark blue enamel.

Nitric or sulphuric acid alone, cannot completely dissolve this oxide; but, a little sugar being added to the nitric acid, enables it superficially to dissolve the oxide, and to separate it from the gold, which then remains clean, and of its natural colour; yet the manganese has only thus been removed from the surface, for, when the mass is cut, the interior exhibits the original gray colour of the mixed metal.

The gold may be purified from the manganese by lead alone, if there is heat and lead sufficient; but this may be more completely and certainly performed, by the mixture of silver, and separation by nitric acid.

As soon as the fine metals are in fusion, the manganese floats upon the surface of the lead, is gradually vitrified, and is absorbed by the cupel, which becomes tinged with a dark blackish-brown colour throughout the whole of its substance; and it must be observed, that this tinge is very different from that afforded by any other metal with which gold may be alloyed.

The cupels on which the manganese has been separated from gold by lead, are corroded in deep holes, by the compound of manganese and lead; an effect which is never observed when copper, or any other of the alloys of gold are destroyed by lead.

The mixture of gold and manganese is more difficult of fusion than gold alone; yet, when the heat is continued with access of air, the whole of the manganese becomes oxidized, and remains on the surface; and, when the mass is cold, it may be separated from the pure gold which is underneath, by the blow of a hammer.

24 carats of the mixed metal, which had acquired $\frac{1}{19}$ of its weight by the absorption of oxygen, was reduced in close vessels, by fusing it with charcoal and oil, as already described.

The manganese again became metallized, and was again combined with the gold, to which it communicated the gray colour and brittleness of the original metal; and the button weighed nearly as at first, viz. 24 carats.

The solution of the mixed metal in nitro-muriatic acid, when evaporated to dryness, leaves a light or pale orange-coloured spongy mass, not so readily deliquescent as the evaporated solutions of pure gold, which are also of a much deeper colour.

The solution of the mixed metal affords, by ammonia, a mixed precipitate, composed of yellow and white particles; but

the mixture of manganese, in this precipitate, does not appear to diminish, or in any way affect, the fulminating property of the gold.

GOLD ALLOYED WITH BISMUTH.

Experiment I.

To eighteen pennyweights and ten grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, when in perfect fusion, were added one pennyweight and fourteen grains of pure bismuth.

The external colour of the metal was pale greenish yellow, like that of bad brass.

It immediately broke under the hammer, and shewed a fine-grained earthy fracture.

Experiment II.

Eighteen pennyweights and ten grains of the fine gold, were alloyed with one pennyweight and six grains of copper, after which, eight grains of bismuth were added.

The ingot appeared, externally, of a pale brownish yellow; it was very brittle, and the fracture was like that of the former, excepting that the grain was not so fine.

Experiment III.

Eighteen pennyweights and ten grains of fine gold, were alloyed with one pennyweight and ten grains of copper, and four grains of bismuth were then added, to complete the standard proportion of alloy.

This metal was, in colour, like gold made standard by copper; it was very brittle, but the grain was coarse.

Experiment IV.

To eighteen pennyweights and ten grains of gold, alloyed with one pennyweight and thirteen grains of copper, one grain of bismuth was added.

The colour of the metal was like that of *Exper.* III. it was very brittle, and, in the fracture, shewed a much coarser grain.

Experiment V.

Eighteen pennyweights of the fine gold, alloyed with one pennyweight and fourteen grains of copper, being completely melted, the button formed by *Exper.* IV. was added, and mixed.

In the two ounces of metal, one grain only of bismuth was present; nevertheless, the ingot was extremely brittle, and the grain of the fracture was remarkably coarse and spongy.

Experiment VI.

To eighteen pennyweights and ten grains of fine gold, alloyed with one pennyweight and fourteen grains of copper, when in fusion, one ounce of the metal formed by *Exper.* V. was added. There now was, at most, not more than $\frac{1}{4}$ of a grain of bismuth in each ounce; but the metal was still brittle, although rather in a less degree than before.

The grain was not spongy; and, as well as the colour, was similar to gold made standard by copper.

From these experiments it appears, that $\frac{1}{4}$ of a grain of bismuth in one ounce Troy of standard gold, or $\frac{1}{1920}$ of the mass, is capable of destroying all ductility; and there is reason to believe, that even a smaller quantity would produce a considerable effect.

The following experiments were made, to ascertain the effects of the fumes or vapour of bismuth upon gold, when melted in close, and when in open vessels.

Experiment VII.

One ounce of the fine gold, being put into a small four-inch crucible, was placed within a large one of about 12 inches, and another large crucible, inverted, was then fixed and luted, in the manner of a dome. One ounce of bismuth was previously put into the inferior large crucible, on the outside of that which contained the gold, after which, a strong heat was kept up during two hours.

Upon opening the vessels, the bismuth was found in a mass, at the bottom of the large crucible; but a considerable part had been volatilized; for the button of gold, which before the experiment weighed 480 grains, now weighed 512,2 grs. and had therefore acquired 32,2 grs. of bismuth. It was, externally, of a pale brassy colour, and immediately split under the hammer, with a coarse-grained fracture.

Experiment VIII.

The preceding experiment was repeated, but without the upper large crucible or dome, so that a free circulation of air was admitted. When half an hour had elapsed, the crucible containing the gold was removed.

The external colour of the button was not altered; but it proved to be so brittle, that it was immediately broken by the first blow of the hammer.

The whole of the foregoing experiments concur to prove, that bismuth, under all circumstances, readily combines with gold, and that it is most exceedingly injurious to the ductility of it.

GOLD ALLOYED WITH LEAD.

Experiment I.

To eleven ounces one pennyweight and three grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, eighteen pennyweights and twenty-one grains of pure lead were added, and, being well mixed, the whole was poured into a mould of iron.

The external colour of the bar was like fine gold, but rather more pale; it had not the smallest degree of ductility, for it broke like glass. The grain was very fine, and of a pale brown colour; it was devoid of metallic lustre, and had a porcellaneous appearance.

Experiment II.

To eighteen pennyweights and ten grains of the fine gold, in fusion, 19 grains of copper were added, and, when the copper was melted and well mixed, 19 grains of lead were also added, to complete the standard proportion of alloy; the metal was then poured into a dry cupel.

The button was, in external colour, like gold made standard by copper; but it immediately broke under the hammer, with an earthy fracture; the grain, however, was not so close as that of the former experiment.

Experiment III.

Eighteen pennyweights of fine gold, were alloyed with one pennyweight and six grains of copper, after which, eight grains of lead were added.

The colour of the metal was like that of the former, but it was perfectly brittle.

The grain of the fracture was rather coarse.

Experiment IV.

Eighteen pennyweights and ten grains of the fine gold, were first alloyed with one pennyweight and ten grains of copper, and afterwards with four grains of lead. This, in colour, resembled the former; it was also as brittle, but the grain was coarser, and shewed some metallic lustre.

Experiment V.

In *Experiments* II. III. and IV. one ounce of standard gold had been prepared, but two ounces were now employed; so that the lead should be in the proportion of one grain to each ounce.

To one ounce sixteen pennyweights and twenty grains of fine gold, when in fusion, three pennyweights and two grains of copper were added, and afterwards two grains of lead.

This ingot resembled the former, and was exceedingly brittle.

Experiment VI.

The ingot formed by the preceding experiment was melted again, with one ounce sixteen pennyweights and twenty grains of fine gold, alloyed with three pennyweights and four grains of copper, so that the lead was in the proportion of $\frac{1}{2}$ a grain in each ounce

The colour was as before; and the metal was very brittle, and of a very loose spongy texture. The latter circumstance explains why the specific gravity amounted only to 16,627.

Experiment VII.

One ounce of the metal formed by *Exper.* VI. was melted with eighteen pennyweights of fine gold, and one pennyweight

and fourteen grains of copper, so that, at most, there could only be $\frac{1}{4}$ of a grain of lead in the ounce.

The colour of this metal resembled the former; and it was also very brittle; but the texture was not spongy, for it was very similar to that of gold made standard by copper.

Experiment VIII.

One ounce of the fine gold, in a small four-inch crucible, was placed within another of 12 inches, at the bottom of which, about two ounces of lead were put on the outside of the small crucible. An inverted crucible, of 12 inches, was then luted on, and the whole was exposed to a strong heat, in a wind-furnace, during two hours.

When the vessels were cold, and were opened, the colour of the gold in the small crucible was found to be unchanged; but, instead of weighing 480 grains, it now weighed 488,1 grs. and was so brittle, that it was immediately broken by the hammer. As so large a quantity of volatilized lead had thus been combined with gold, in close vessels, the following experiment was made with the free access of air.

Experiment IX.

One ounce of fine gold, in a small crucible, was placed within another of 12 inches, containing about four ounces of lead, which, remaining open, was exposed to a strong heat in a wind-furnace, during half an hour.

The gold in the small crucible was afterwards examined; and the external colour was found to be but little changed; the ductility of it was also not much injured, for, when repeatedly hammered, it only cracked slightly on the edges.

These experiments with lead, prove how destructive it is to the ductility of gold; and that the properties of it, in this and many other respects, much resemble those of bismuth, excepting that the latter has a more powerful effect, when reduced to vapour in the vicinity of melted gold.

Bismuth, as well as lead, when combined with gold in certain proportions, produces some remarkable effects upon the texture and specific gravity of the latter metal; and these effects are the most conspicuous, when either of the former metals is in the proportion of half a grain in the ounce Troy of gold alloyed with copper; for then the alloyed gold becomes remarkably spongy, and suffers a very considerable diminution of specific gravity.

GOLD ALLOYED WITH TIN.

Experiment I.

Eleven ounces one pennyweight and three grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, being melted, eighteen pennyweights and twenty-one grains of pure grain tin were added, and, when well mixed, the whole was poured into a mould of iron.

The bar was in some measure brittle; but, as this appeared to be partly caused by the thickness, ($\frac{1}{4}$ of an inch,) the experiment was repeated as follows.

Experiment II.

The same bar was melted again, and was cast in sand, so as to form a bar only $\frac{1}{8}$ of an inch in thickness.

This appeared to bend so easily, that it was passed between the rollers, but it then broke longitudinally into several pieces.

The external colour of the bars, in both experiments, was very pale whitish yellow.

The grain of the fracture was fine, inclining to an earthy appearance, and was of a pale yellowish-gray colour.

Experiment III.

Eighteen pennyweights and ten grains of fine gold, alloyed with 19 grains of copper, being melted, 19 grains of fine grain tin were added, and, being properly mixed, the metal was poured into a cupel.

The button was, externally, pale yellow; and it soon broke under the hammer, with a close-grained and rather earthy fracture.

Experiment IV.

To eighteen pennyweights and ten grains of the fine gold, alloyed with one pennyweight and six grains of copper, in fusion, eight grains of pure tin were added, and treated as before.

This metal resembled, in colour, gold made standard by copper, excepting that it was rather paler; it also proved to be perfectly ductile.

Two pounds of gold were afterwards alloyed with tin and copper; the former was in the proportion of eight grains in the ounce, similar to the last experiment; and, in like manner, the alloyed metal was found to be perfectly ductile; so that the bar, which at first was $\frac{1}{4}$ of an inch in thickness, was rolled as thin as a guinea, and, when thus rolled, it still remained so soft, that it was punched and stamped without being previously annealed.*

* It has been suggested, that tin might be advantageously employed as an alloy for silver coin; but, by some experiments which I purposely made, I found the fact to be the reverse; for, when silver was alloyed with the standard proportion of tin, it proved brittle, and did not ring well; and the same defects prevailed, when an alloy composed of equal parts of tin and copper was employed.

It is therefore certain, that tin, in small quantities, or even in the proportion of eight grains in the ounce Troy, is not by any means so injurious to the ductility of gold as was generally believed, previous to the publication of Mr. ALCHORNE'S Paper, in the Philosophical Transactions for the year 1784.*

Some time after the experiments lately described were made, ROBERT BINGLEY, Esq. his Majesty's Assay Master at the Mint, communicated to me the following experiments, made by him, in consequence of a paper published in the Memoirs of the Academy of Sciences at Paris for the year 1790, and in NICHOLSON'S Philosophical Journal, Vol. II. p. 140 and 179.

The author of this paper, Mr. TILLET, a gentleman of much eminence in science, after having related some experiments which he purposely made upon mixtures of gold and tin, states it as his opinion, that tin, in small quantities, is really injurious to the ductility of gold, especially when gold thus alloyed is subjected to what he terms a cherry-red annealing heat; and this circumstance, he conceives to have been overlooked by Mr. ALCHORNE.

Mr. BINGLEY, whose professional accuracy is sufficiently

* GELLERT asserts, that even the fumes of tin destroy the ductility of gold. Metallurgic Chemistry, p. 368. The same opinion may also be found in the following works.

Docimasie de SCHLUTTER, *traduit par* HELLOT, p. 284. *E'lémens de Docimastique par* CRAMER. Tome I. p. 142. NEUMANN'S Chemistry, Vol. I. p. 49; and, in page 125 of the same volume, he says, "the minutest portion, even the vapour of "tin, renders many ounces, and even pounds, of gold and silver, so brittle as to fall in "pieces under the hammer The least particle of tin falling on the stones or luting "of a furnace, will make all the gold and silver melted in it hard and brittle. From "such an accident, the gold and silversmiths are obliged to pull down the whole "furnace, and build a new one with fresh materials."

known, therefore made the following experiments, in order to investigate the subject in dispute.

MR. BINGLEY'S EXPERIMENTS UPON GOLD ALLOYED WITH TIN.

I.

"Two bars of gold alloyed with tin, in the proportion of "eight grains in the ounce Troy, and which had passed the "steel rollers without any disposition to break on the edges, "were submitted to an annealing heat, under a muffle, at two "different temperatures.

"The first bar was exposed to a low degree of heat, visibly "red by daylight, which contracted WEDGWOOD'S pyrometer "five degrees.

"At this temperature, the metal was sufficiently annealed, "had lost the sonorous property acquired by passing the rollers, "was quite ductile, and capable of being worked into any form; "and was slightly discoloured or oxidized on the surface.

"The second bar was subjected to a somewhat greater heat, "approaching the cherry-red described by Mr. TILLET, and "which contracted the pyrometer ten degrees.

"At this temperature, some sensible changes soon began to "take place; and, by a constant attentive watching of the metal "during this exposure, three gradations of mischief were evi- "dently marked.

"1st. Little distinct bubbles or blisters arose in different "places on the surface.

"2dly. The whole bar, in a short time, began to curl up, or "warp, on the edges. And,

"3dly. When the whole of the tin, diffused through the "interior of the metal, might be supposed to be in fusion, a

" solution of continuity followed; for the bar, by its own weight, " fell from the supporters on which it was placed, in a rough " dark-coloured mass, having scarcely any appearance of metal, " although it recovered its metallic lustre, and some tenacity, by " being hammered upon a polished anvil.

II.

" These experiments were repeated, with exactly the same " results; and seem to prove, beyond a doubt, that gold alloyed " with tin may be repeatedly annealed, after passing the rollers, " without any danger, provided that due attention be paid to " the temperature to which it is exposed.

" Hence it may fairly be said, that all which Mr. TILLET has " advanced on the foregoing subject, if closely attended to, will " be found to go in confirmation of what Mr. ALCHORNE had " previously asserted, relative to the mixture of gold with tin; " and Mr. TILLET only adduces the additional fact, of a greater " degree of heat destroying the union of the two metals, which, " from a full consideration of their peculiar properties, and dif- " ferent fusibility and specific gravity, might have been inferred " *a priori*. It is also reasonable to suppose, that whenever a " combination of a more with a less fusible metal takes place, " a temperature insufficient to fuse the whole mass would tend " to separate the one from the other; and this is the principle " on which the process of eliquation depends.

" Mr. ALCHORNE was induced to make the experiments on " tin and gold, from reading the following passages. ' A single " grain of tin will destroy the ductility of a thousand grains of " gold, rendering the most malleable gold incapable of being " extended, and of bearing the hammer at all.' NEUMANN's " Chemistry, Vol. I. p. 49.

" 'Of tin and lead, the most minute portions, even the va-" pours which rise from them in the fire, though not sufficient " to add to the gold any weight sensible in the most delicate " balance, make it so brittle, that it flies to pieces under the " hammer.' Lewis's Philosophical Commerce of Arts, p. 85."

There must have been, undoubtedly, some cause from whence originated the general and universal opinion, that tin was so injurious to the ductility of gold, although it is now evident that this opinion is, within certain limits, erroneous; and it appears to me very probable, that the chemists and metallurgists who first promulgated the idea that the ductility of gold was destroyed even by the fumes of tin, made their experiments with tin which contained a small portion of bismuth, lead, antimony, or zinc; and, as the foregoing experiments have proved, that even less than $\frac{1}{1920}$ of the three first of these metals is sufficient to make gold very brittle, and that gold in fusion attracts and combines with them, when in a state of vapour, we may suspect these to have produced the principal part of the effect which has been attributed to tin, and which has been so generally asserted and believed.

As to the difference of opinion between Mr. Alchorne and Mr. Tillet, it seems that both these gentlemen have just grounds for their assertions; and that the different degree of annealing heat, employed by the one and by the other, has been the cause, why the results of their experiments appear to be so opposite.

GOLD ALLOYED WITH IRON.

The effects of iron upon gold seem to have been less understood, and more erroneously stated, than even those of tin. For

it has been so repeatedly asserted by various chemists, and so universally believed by all persons concerned in the melting and working of gold, that the ductility of it is destroyed, or much injured, by very small portions of iron, that, had it not been for the determination made, when these experiments were begun, to examine, by experiments made expressly for the purpose, every assertion respecting the effect of alloys, this long established opinion would not here have been questioned.

Indeed, considering how easy it was to ascertain whether or not gold could be rendered brittle by the addition of iron, it is a matter of astonishment, when we read in the works of many celebrated chemists, and when we hear intelligent and judicious artists assert, that iron, even in minute proportions, injures or destroys the ductility of gold.*

It is not necessary here to inquire how this erroneous idea first originated; but, that the fact is absolutely the reverse, the following experiments will sufficiently prove.

Experiment I.

To eleven ounces one pennyweight and three grains of gold, 23 car. $3\frac{1}{2}$ fine, eighteen pennyweights and twenty-one grains of clean iron wire were added.

The iron was soon melted, and was well mixed with the gold, after which, the whole was poured into a greased mould of iron.

* "Le fer qui y touche, (l'or,) quand il est en fusion, *l'aigrit aussi,* au lieu qu'il "adoucit l'argent." SCHLUTTER, p. 284.

"Iron or steel, in a very small proportion, render gold hard and eager, and, on "increasing the quantity of the iron, the mixt continues *brittle.*" LEWIS's Phil. Comm. of Arts, p. 85.

"When gold is fused with iron, it is by it rendered pale and *brittle.*" GREN's Principles of Modern Chemistry, Vol. II. p. 339.

The bar thus formed was of a pale yellowish gray, approaching to a dull white; it was very ductile, and, with great ease, was reduced by the rollers from $\frac{1}{4}$ of an inch to the thickness of a guinea. It was then cut without difficulty, by the punches, into blanks, and these were afterwards stamped with great ease, although they had not been annealed.

Experiment II.

The same bar was again melted, and was cast in a sand mould; it then appeared to be very brittle, but this, it was proved, was occasioned by the effects of the sand mould, which had rendered the metal porous; for, when the parts had been approached by previous hammering, the bar was rolled, and, in every respect, was found to be as ductile as in the former experiment.

Experiment III.

Eighteen pennyweights and ten grains of the fine gold being melted, one pennyweight and fourteen grains of cast-iron nails were added, and, when fused, the whole was cast in a mould of iron.

This metal, in colour, much resembled the former; and was also perfectly ductile.

Experiment IV.

This was the same as *Exper.* III. but thin plate cast-steel was employed, instead of cast-iron.

The properties of this metal, in respect to colour, ductility, &c. resembled the former.

Experiment V.

To eighteen pennyweights and ten grains of fine gold, alloyed

with 19 grains of copper, 19 grains of fine iron wire were added, and the mixture was treated as before.

The colour of this metal was pale grayish yellow; it was perfectly ductile, and was rolled and stamped, without being previously annealed.

By these experiments it appears, that gold made standard by wrought and cast iron, and even by cast-steel, is not brittle, as has generally been asserted; for, although gold undoubtedly is thus rendered harder, it nevertheless does not become brittle, but remains so ductile, that it may be hammered, rolled, and stamped, without requiring to be annealed; and, allowing that the change of colour produced by iron upon gold renders it unfit for coin, yet this mixture may probably be employed with advantage in ornamental and other works.*

Emery is enumerated by mineralogists among the ores of iron; and many very intelligent assayers, and others, even at this time, believe it to be a frequent cause of the brittleness of gold.

Some eminent metallurgists, such as SCHLUTTER, support the same opinion, and have recommended certain processes to be employed to refine the gold, when thus adulterated.† It must however be allowed, that it is not easy to conceive how such a combination can take place; for if (as is generally believed) emery consists of oxide of iron and siliceous earth, such a substance cannot unite with gold in the metallic state; and, even supposing that the ferruginous ingredient could in any manner be combined with gold, yet it has been fully proved, in another

* It is said that this mixture is sometimes employed by goldsmiths.

† SCHLUTTER, *Docimasie,* p. 282.

part of this Paper, that gold does not become brittle by the addition of iron. In order, however, to ascertain what effects could be produced by emery,* the following experiments were made.

EXPERIMENTS ON EMERY AND GOLD.

Experiment I.

One ounce of fine gold was put into a small crucible, and was completely covered with emery, which had been reduced to a fine powder.

The gold was kept in fusion during one hour, and was frequently stirred, after which, it was poured into a mould.

Not the smallest change, in colour, ductility, or any other property, was thus produced.

Experiment II.

About half an ounce of fine powder of emery was, several times, alternately moistened with olive oil and made red hot, after which, it was put into a crucible lined with charcoal.

* Mr. TENNANT has lately shown, (Phil. Trans. for 1802, page 400,) that emery is composed of alumina, silica, and iron. In one case, he obtained,

Alumina - - -	80
Silica - - - -	3
Iron - - - -	4
Residuum - - -	3
	90.

And, from another variety, more impregnated with iron, he obtained,

Alumina - - -	50
Silica - - - -	8
Iron - - - -	32
Residuum - - -	4
	94.

An ounce of fine gold was placed in the middle of the emery; the crucible lined with charcoal was closed by a stopper of the same, and a cover was luted upon the exterior crucible.

After a very strong heat of one hour and a half, the gold was found to be exactly of the same colour, ductility, &c. as before.

Experiment III.

The preceding experiment was repeated; but the heat was continued during three hours, so that at length the crucible began to be melted.

It was suffered to cool in the furnace; and, being afterwards broken, the gold was found crystallized in a reticulated form, but not altered in colour or ductility. The emery was reduced to a dark gray or blackish slag, which occupied the upper part of the crucible.

We have, from the above described experiments, sufficient proof that emery will not combine with gold; and, when the difficulty of uniting metallic oxides in general, or any earthy substance, with a metal, is considered, it appears singular that the existence of such a combination as that of emery with gold should ever have been believed.

It is not however improbable, but that some other substance has been occasionally denoted by the term smiris, emeril, or emery; and Dr. Lewis appears to be inclined to adopt this opinion.*

GOLD ALLOYED WITH PLATINA.

Experiment I.

Eighteen pennyweights and ten grains of gold, 23 car. $3\frac{1}{2}$ grs.

* Phil. Comm. of Arts, p. 607.

fine, being completely melted, one pennyweight and fourteen grains of purified platina were added, and, when well mixed, the whole was poured into a mould.

This metal was of a yellowish white, like tarnished silver, and was extremely ductile.*

The specific gravity of it was 19,013.

Experiment II.

The ounce of standard gold formed by the foregoing experiment, was again alloyed with one pennyweight and fourteen grains of copper, so that the standard proportion of alloy was doubled.

This metal was of a pale dull yellow; it was not quite so ductile as the former; and the specific gravity was 16,816.

It was not thought necessary to extend these experiments, as the properties and effects of platina upon gold are now so generally known, as well as the means usually employed to detect it.†

* The platina had been purified by precipitation with muriate of ammonia, and was therefore in the state of a fine metallic powder, which probably contributed much to facilitate the union of it with the gold. I must observe, however, that it was not absolutely pure, for it still contained a small portion of iron.

The specific gravity of this platina was 18,717.

Gold made standard by platina, is not only very ductile, but also (when hammered) tolerably elastic. Perhaps it might be advantageously employed for the springs of watches, &c.

† Quand le platine ne surpasse pas les 30 à 40 millièmes de son alliage avec l'or, ce dernier n'en garde point, si le départ est fait avec les précautions nécessaires; et, lorsque ce métal est au-dessus de ce terme, la fraude devient trop sensible et trop évidente, pour qu'on ne s'en apperçoive pas; 1mo, par la plus grande chaleur que l'essai demande pour passer et prendre une forme arrondie; 2do, par l'absence de l'éclair; 3mo, par la surface crystallisée, et la couleur blanche et matte du bouton; 4mo, par la couleur jaune de paille, plus ou moins foncée, qu'il communique à l'eau-forte pendant

GOLD ALLOYED WITH COPPER.

Experiment I.

Eleven ounces one pennyweight and three grains of gold, 23 car. $3\frac{1}{2}$ gr. fine, were alloyed with eighteen pennyweights and twenty-one grains of the finest Swedish copper.

The heat employed was only just sufficient to keep the whole in fusion; and, when the alloy appeared to be well mixed, the metal was poured into a greased mould of iron.

The standard gold, thus formed, was perfectly ductile, and of a deep yellow colour, inclining to red.

Experiment II.

The bar formed by the preceding experiment was melted in the strongest heat which could be excited, and was again cast in the mould of iron.

Not any alteration, however, appeared to have been produced by the increased heat.

Experiment III.

The bar was again melted, and was then cast in sand; but still the ductility and other properties remained as before.

From these experiments it appears, that gold made standard by copper, does not suffer any change in ductility by the different degrees of heat, nor by the nature of the moulds in which the metal is cast, provided that the copper be pure.

Experiment IV.

Eleven ounces one pennyweight and three grains of fine gold,

le depart; 5mo, enfin par la couleur jaune pâle, et tirant au blanc, du cornet, quand il est recuit. *Manuel de l'Essayeur, par* VAUQUELIN, p. 49.

were alloyed with eighteen pennyweights and twenty-one grains of granulated Swedish copper, which was taken from another parcel.

The bar was cast in a mould of iron, and was found to be, in a small degree, less ductile than the metal formed by the foregoing experiments.

Experiment v.

The same bar was melted again, and was cast in sand, faced in the usual manner by charcoal dust; it then proved slightly brittle.

Experiment vi.

The bar was melted as before, and was cast in the mould of iron.

The metal was now found to have recovered the same ductility which it possessed in *Exper.* iv.

Experiment vii.

Eleven ounces one pennyweight and three grains of fine gold, were alloyed with eighteen pennyweights and twenty-one grains of Swedish dollar copper, which being well mixed, the whole was cast in a mould of iron.

The colour of this bar resembled the former; but it did not possess the smallest degree of ductility, for it broke like glass.

Experiment viii.

The bar was melted again, and was cast in sand; but not any alteration was thus produced.

Experiment ix.

The foregoing bar was melted once more, and was cast in the mould of iron; but it still remained as brittle as at first.

Experiment X.

One pound Troy of standard gold was made as already mentioned, and another Swedish copper dollar was employed for the alloy.

The metal was cast in a mould of iron, and proved to be ductile; it is therefore very evident that the Swedish copper dollars are not of an uniform quality.

Experiment XI.

Eleven ounces one pennyweight and three grains of the fine gold, were alloyed with eighteen pennyweights and twenty-one grains of fine British granulated copper.

When this was cast in a mould of iron, it was found to be slightly brittle.

Experiment XII.

When the same bar was cast in sand, the brittle quality was much increased.

Experiment XIII.

Eleven ounces one pennyweight and three grains of fine gold, were alloyed with eighteen pennyweights and twenty-one grains of British granulated copper which was considered as better than the former.

The bar was cast in the mould of iron, and was very ductile.

Experiment XIV.

The same bar being melted, was cast in sand, and then was found to be brittle.

Experiment XV.

The abovementioned brittle bar was again melted, and was cast in the mould of iron.

It then became ductile, but not quite in so great a degree as in *Exper.* XIII.

Experiment XVI.

Six ounces of fine gold, and six ounces of the finest Swedish copper, were melted, and mixed. This metal, being cast in the mould of iron, was ductile.

Experiment XVII.

The bar was melted again, and, being cast in sand, was then found to be very brittle.

From these experiments it appears, that the varieties of copper in commerce, although similar in aspect, and other obvious properties, are far from being uniform in quality; so that many of them are by no means sufficiently pure to be employed as an alloy for gold.

Moreover, the different effects produced by the moulds of iron and those of sand, are such as fully prove, that copper which is not perfectly pure, and which has a tendency to render gold brittle, acts more powerfully, in this respect, when the alloyed mass is cast in sand than when it is cast in iron; and, all things being considered, we have reason to conclude, that moulds of iron are much to be preferred to those of sand.*

The ores of antimony and of lead frequently accompany those of copper; and it has already been proved, that $\frac{1}{1920}$ of either

* Bars of alloyed gold (particularly those which are alloyed with copper) are generally discoloured on the surface, when cast in moulds of sand; but not so when cast in iron. It may be suspected, that the alloy is superficially oxidized when sand is employed, in consequence of the air which is lodged in the interstices, together, perhaps, with some degree of moisture.

of the former metals is sufficient to destroy the ductility of gold. It may therefore be suspected, that the brittle quality which certain kinds of copper communicate to gold, proceeds from those metals; for, although other metallic substances produce the same effect, yet, as the former especially are so commonly present with the ores of copper, it is highly probable that antimony, or lead, may remain combined with the smelted copper, in a proportion too small to affect the general and more obvious properties of that metal, yet still sufficient to destroy the ductility of gold, when such copper is employed as an alloy.

To ascertain how far copper might be alloyed with lead, or antimony, without any very apparent change in its obvious properties, the following experiments were made.

To 476 grains of fine malleable copper, in fusion, four grains of antimony were added, and, being well mixed, the whole was poured into a mould.

The colour of this copper, when filed and polished, was such as not easily to be distinguished from that which had not been thus alloyed.

It was also hammered and rolled, without shewing any signs of brittleness. The specific gravity was 8,354.*

The like quantity of copper was alloyed with four grains of lead.

This also was ductile, and did not suffer any apparent change of colour.

The specific gravity was 8,472.

The same experiment was repeated with four grains of bismuth; but the copper thus alloyed was exceedingly spongy and brittle.

* The finest Swedish copper was employed in these experiments; the specific gravity of it was 8,895.

It appears, therefore, that four grains of antimony, or of lead, may be present in one ounce, or 480 grains, of copper, without producing any very apparent change in colour or ductility, and but little in specific gravity; such copper may, therefore, without suspicion, be occasionally employed to alloy gold; then, however, the antimony or lead will produce a powerful effect; for it has been proved, that $\frac{1}{1920}$ of either of these will destroy the ductility of gold. But, supposing one ounce Troy of copper which contains four grains of antimony, or of lead, to be employed to alloy eleven ounces of gold, 24 carats fine, there would then be four grains of the abovementioned metals in the 12 ounces or Troy pound; and therefore the quantity of these would be considerably more than is required to destroy the ductility of gold. For the Troy pound contains 5760 grains; and 4 is to 5760 as 1 to 1440; consequently, this proportion much exceeds the quantity which is capable of producing the abovementioned effect.

But the copper of commerce often contains a much greater proportion of one or other of these metals; and, although it then appears more pale than common, yet it has, without suspicion, been purchased by those who, from their profession, are supposed to be competent judges, and who especially require copper to be as pure as possible. Persons of this description, however, are liable to be deceived; for, in 1791, Mr. Roitier, Director of the Mint at Paris, purchased a quantity of copper from the mines of Poullaoen in Britany; but he soon discovered, from the effects which it produced, when employed as an alloy, that it was not pure, and therefore requested Mr. Sage to examine it. By the latter, it was analysed, and was found to contain one forty-eighth of antimony.*

* *Journal de Physique*, 1792, Tome XL. p. 273.

Allowing, therefore, that other metallic substances may at times be present in copper, and may contribute to affect gold which is alloyed with it, yet, for the reasons above related, I am inclined to attribute, most frequently, this effect to antimony or lead.*

* Copper which is pure, is uniform in its effects, and does not injure the ductility of gold; it would therefore be proper, in all cases when copper is to be purchased for the purpose of alloying gold, to make a previous trial of it on a small quantity, as this would answer every purpose of a tedious and expensive analysis.

Since the above was written, I have made various experiments in the humid way, on the different kinds of copper which are known in commerce, especially on the following:

No. 1.	Finest granulated Swedish copper - -	sp. grav. 8,895.
2.	—— Swedish dollar copper - - -	sp. grav. 8,799.
3.	—— sheet British copper - - -	sp. grav. 8,785.
4.	Fine granulated British copper - - -	sp. grav. 8,607.

480 grains of the first, only afforded a few particles of sulphate of lead, which could not be estimated.

The second contained both lead and antimony, of which the lead was in the largest proportion, as it amounted to nearly one grain of metallic lead, whilst the antimony did not exceed half a grain.

The sheet British copper yielded some lead, with scarcely any antimony; and, on the contrary, the granulated British copper contained antimony with but very little lead. We may therefore conclude, that the varieties of copper known in commerce, are seldom, if ever, absolutely free from lead or antimony; and that the brittle quality, so frequently communicated to gold by an alloy of copper, arises from the presence of one or both of these metals, which, even in the proportion of $\frac{1}{1920}$ part of the mass, I have already proved to be capable of destroying the ductility of gold.

I have lately made some farther inquiries concerning the varieties of Swedish copper, and am informed, that the fine granulated copper is made in this country from the Swedish cake-copper, merely by the ordinary process of granulation; and, as the quality even of this copper has been found variable, the Deputy Master of the Mint has of late employed British copper, which has been refined expressly for the purpose, and seems to answer perfectly well. Respecting the variable and occasional very bad quality of the copper dollars, Mr. SWEDENSTIERNA, a learned Swedish gentleman

GOLD ALLOYED WITH SILVER.

Gold alloyed with pure silver, in standard proportion, is so generally known, that it would be needless here to say more, than that it approaches the nearest to the ductility of fine gold, and that the specific gravity of this mixture differs but very little from that which, according to calculation, would result from the relative proportions of the two metals.

From the foregoing experiments it is evident, that many of the metallic substances with which gold may be alloyed, are more or less liable to be separated from it during fusion, in consequence of their relative affinities with caloric, with oxygen,

at present in London, has favoured me with some particulars, in a letter, of which the following is an extract.

" Puis, par rapport au dollars, je serais bien surpris si jamais ils avaient été parfaitement purs, parce que, tant que je sais, ils ont toujours été frappés de cuivre de Fahlun, dont le minerais a toujours été plus ou moins melangé de plomb sulfuré, et peut-être d'antimoine. Cependant, comme ces dollars avaient été frappés originairement sous le regne du Roi FREDERIC, (FREDERICUS Rex Sueciæ,) et que dans ce tems là on aurait pu employer un minerais plus pur a Fahlun, il est probable que ces dollars, dans leur origine, ont été meilleurs que ceux contrefaits depuis; car ces dollars ayant été recherchés aux Indes, et surtout commandés en assez grande quantité par la Compagnie Asiatique de Copenhague, on en a frappé de nouveau, à plusieurs reprises, et de toute sortes de cuivre indifféremment. Ce fait explique au moins la cause de leurs inegalités de composition.

" Reste à savoir, si jamais on en a trouvé de parfaitement purs. Pour moi, je suis plus porté à croire, que c'est la convenance de la forme de ce cuivre qui l'a mis au courant dans les Indes, et que ce sont les prejugés qui lui ont donné du credit pour l'usage de la monnoie. Depuis quelques années, les Danois, ayant trouvé ce cuivre trop cher, en ont contrefait la marque eux mêmes, et en ont frappés a Roeraas, en Norwege; ce qui doit fournir encore une variété de ce cuivre."

or with both; and that these affinities become modified, by those which prevail between the various metallic substances and gold. Moreover, it is evident, that even the most oxidable metals have this property much diminished or checked by being united with gold, which appears so to envelope and retain their particles, as to impede the usual influence of heat, as well as the natural exertion of their affinities with the oxygen of the atmosphere. The following experiment was therefore made, to ascertain the comparative loss caused by the volatilization, or by the oxidizement of various metallic substances, when added to gold during a given period of fusion, and under similar circumstances.

Experiment.

Ten four-inch crucibles, which had been previously made red-hot, were put into as many 12-inch crucibles, which were placed in wind furnaces of similar construction, and heated as equally as possible. Each of the small crucibles contained five ounces ten pennyweights and fourteen grains of gold, 23 car. $3\frac{3}{4}$ grs. fine, which being completely melted, nine pennyweights and ten grains of the following metals were added, and mixed in the usual manner, after which, the fusion was continued in the open vessels during one hour.

The different masses, when cold, were weighed; but, previous to this, the scoria or glass which had been formed on some of them was gently removed. The comparative loss will appear from the following Table.

TABLE.

Weight of the Gold, and of the Alloy, before fusion.				Total Weight.	Weight of the Mass, after fusion.			Loss upon 6 oz.		
	car.	grs.		Ounces.	oz.			oz.	dts.	grs.
1. Gold,	23	$3\frac{3}{4}$ fine -		6	6			0	0	0
	oz.	dts.	grs.							
2. Gold -	5	10	14	6	6			0	0	0
Fine silver -	0	9	10							
3. Gold -	5	10	14	6	6			0	0	0
Copper -	0	9	10							
4. Gold - -	5	10	14	6	6			0	0	0
Tin - -	0	9	10							
					oz.	dts.	grs.			
5. Gold - -	5	10	14	6	5	19	21	0	0	3
Lead - -	0	9	10							
6. Gold - -	5	10	14	6	5	19	12	0	0	12
Fine iron -	0	9	10							
7. Gold - -	5	10	14	6	5	19	12	0	0	12
Bismuth -	0	9	10							
8. Gold - -	5	10	14	6	5	19	12	0	0	12
Antimony -	0	9	10							
9. Gold - -	5	10	14	6	5	19	0	0	1	0
Zinc - -	0	9	10							
10. Gold -	5	10	14	6	5	10	12	0	9	12
Arsenic -	0	9	10							

According to the foregoing Table, it appears, that fine gold, gold alloyed with silver, gold alloyed with copper, and gold alloyed with tin, did not suffer any loss during the experiment.

Moreover, that gold alloyed with lead only lost three grains, chiefly by vitrification.

That gold alloyed with iron lost 12 grains, which formed scoria.

That gold alloyed with bismuth also lost 12 grains, chiefly by vitrification.

That gold alloyed with antimony lost the same quantity, partly by volatilization, and partly by vitrification.

That gold alloyed with zinc lost one pennyweight, by volatilization. And,

That gold alloyed with arsenic, not only lost the whole quantity of alloy, but also two grains of the gold, which were carried off in consequence of the rapid volatilization of the arsenic.

LEWIS, (Phil. Comm. of Arts, p. 88,) however, asserts that "gold is more volatilized by antimony than by arsenic or zinc; "but to produce this effect the fire must be vehement, the "crucible shallow, and the air strongly impelled." These circumstances, according to their variations, must undoubtedly very much influence the results of such experiments; and therefore, although the reverse was found to take place in the experiments here stated, it does not follow that certain changes should not be produced by different degrees of heat, by the figure of the vessels, and by a current of air more or less strong.

The whole of the experiments of this section tend to prove, that (agreeably to general practice and opinion) only two of the metals are proper for the alloy of gold coin, namely, silver and copper; as all the others either considerably alter the colour, or diminish the ductility, of gold. In respect to the latter quality,

the different metallic substances which have been employed in the present experiments, appear to affect gold nearly in the following decreasing order.

1. Bismuth.
2. Lead. } These are nearly equal in effect.
3. Antimony.
4. Arsenic.
5. Zinc.
6. Cobalt.
7. Manganese.
8. Nickel.
9. Tin.
10. Iron.
11. Platina.*
12. Copper.
13. Silver.

Before I conclude this section, I must observe, that the subject of alloys has not in general been sufficiently investigated by chemists; and I therefore should have been glad to have repeated the preceding experiments intirely in close vessels, and with many other precautions; but, from various circumstances, I have been obliged, for the present, to content myself with what has been here related; and, although I have not been able to do all I could have wished, I yet flatter myself that these experiments will tend to remove certain prejudices and erroneous opinions, and that they will be found to be of some utility.

* Had the platina been quite pure, the compound metal would probably have possessed more ductility; I cannot therefore take upon me to assert positively, that the place here assigned to platina, is precisely that which it ought to occupy.

SECTION II.

ON THE SPECIFIC GRAVITY OF GOLD, WHEN ALLOYED BY VARIOUS METALS.

The many difficulties which attend the making of experiments intended to ascertain the specific gravity of bodies, with any tolerable degree of precision, are sufficiently known to every one who has had practical experience; and some of these difficulties have been ably pointed out, and avoided, by Sir GEORGE SHUCKBURGH EVELYN, Bart. F. R. S. in his valuable Paper, entitled An Account of some Endeavours to ascertain a standard of Weight and Measure. Phil. Trans. for 1798, p. 133. In fact, when we consider the inaccuracies of balances, and the effects produced by the different height of the column of water, and by the changes of temperature to which the water is exposed during the experiments, we have less reason to be surprised at the frequent variations in the results; and, in addition to these sources of error, if we consider the different texture of bodies, and the numberless interstices of them, often unequally arranged, and which cannot at all times be penetrated by water, we may rather wonder that so much precision has been attained. The last-mentioned obstacles to exactitude in such experiments, are peculiarly to be observed, when the specific gravity of certain substances, such as stones and ores, is to be determined; and, although the metals, being in general more dense, are supposed to be less liable to such variations in internal texture, yet it is acknowledged, that the specific gravities of these, as stated by various authors, cannot be regarded as exact; and indeed, from the following experiments, I think it will

appear evident, that extreme precision and uniformity in the results, can seldom be attained or expected.

When metals are cast in a mould, they speedily become cold; and, according to the quantity and quality of the metal, the figure and position of the mould, and the greater or less rapidity of the cooling, metals may vary in texture, and in the relative proportion and arrangement of their interstices; and consequently the mass, in different parts, may be of unequal degrees of density. For, a metal of an uniform quality in other respects, generally becomes most dense in the bottom of the mould, especially when a long bar of heavy metal is cast in a vertical position.

Those metals which are very ductile, may, by hammering and rolling, be brought more nearly to a certain uniform density; for the number and capacity of the interstices, or air-bladders, in the interior of the mass, are thus more or less diminished; and, although the brittle metals, or semimetals, as they are improperly called, cannot be thus treated, yet, when reduced to powder, or into small fragments, they expose a large surface, and consequently the error produced by interstices or cavities is much reduced.*

But, neither hammering, rolling, nor pulverization, can be applied to those metallic substances, whether simple or mixed,

* The interstices and cavities here mentioned, are those only which are formed during melting and casting; for the natural grain and texture peculiar to each metal, cannot be changed by any of the methods employed to correct the irregularities which have been accidentally introduced; and it appears proper to remark, that without very great caution, a new source of error may arise from the reduction of brittle metals into small fragments, or powder, which may conceal and retain little bubbles of air, so obstinately adherent to the metallic particles, as to require great patience and perseverance before they can be properly and completely disengaged.

which are neither sufficiently malleable to be rolled, nor sufficiently brittle to be reduced into powder; and this last difficulty most frequently occurs in mixed or alloyed metals.

It is well known, that the specific gravity of an alloyed metal is seldom that which, by calculating the respective specific gravities and proportions of the different metals, would be the result; on the contrary, the specific gravity of the alloyed mass, is frequently greater or less than it ought to be, according to calculation.

This effect has been often noticed by various authors; and it is not requisite that I should here repeat facts already so well established; I have, however, thought it proper to state, in the following pages, the changes in specific gravity which took place, when gold was alloyed with different proportions of various metals.

In the following experiments, I employed a very accurate balance, which was made for me by Mr. HAAS, and which, when loaded with 1000 grains at each end, turned with $\frac{1}{200}$ of a grain.

The vessel containing distilled water, at 60° of FAHRENHEIT, was covered with flannel, in order to avoid, as much as possible, any change of temperature produced by the circumambient air; and every other precaution was taken, as is usual, when such experiments are to be made.*

* Each experiment was most commonly made upon one Troy ounce of alloyed metal; but in some cases two ounces were employed. The different ingots and bars were also carefully examined, and were cut, in order to discover any cavities or air-bladders in their interior.

TABLE I.

Gold variously alloyed.				Specific Gravity.
	oz.	dts.	grs.	
Gold, 23 car. $3\frac{3}{4}$ grs. fine, which had been rolled and stamped				19,277.
Gold, 23 $3\frac{1}{2}$ fine, in the bar				19,172.
Gold, 23 $3\frac{1}{2}$ fine	0	18	10	19,013.
Platina*	0	1	14	
Gold, 23 $3\frac{1}{2}$ fine	0	18	10	16,816.
Platina	0	1	14	
Copper	0	1	14	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,927.
Pure silver	0	1	14	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,344.
Pure silver	0	0	19	
Copper	0	0	19	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,157.†
Copper	0	1	14	
Gold, 23 $3\frac{1}{2}$	0	18	10	16,885.‡
Pure wrought iron	0	1	14	

* The specific gravity of the platina was 18,717; and it has been already remarked, that it contained a small portion of iron.

† The experiments upon gold made standard by silver, by silver and copper, and by copper alone, were made upon whole and complete ingots, which had been mixed and cast with the greatest care, and which, separately, weighed two ounces Troy.

‡ If this metal had been cast in sand, it would have been porous, and the specific gravity would have been less than is stated in the table; on this account, sand moulds were not employed in these experiments.

The mould of iron, which has been so frequently mentioned, was not a common open ingot mould, but was a box of polished wrought iron, with a lid, which was ground so as to be air-tight. The mouth was at one end; and a bar cast in this mould measured 12 inches in length, one inch in breadth, and $\frac{1}{4}$ of an inch in thickness.

TABLE I. *(continued.)*

Gold variously alloyed.	car.	grs.	oz.	dts.	grs.	Specific Gravity.
Gold,	23	$3\frac{1}{2}$	0	18	10	16,840.
Cast steel			0	1	14	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,125.
Pure iron			0	0	19	
Copper			0	0	19	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,307.
Tin			0	1	14	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,278.
Tin			0	0	19	
Copper			0	0	19	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,352.
Copper			0	1	6	
Tin			0	0	8	
Gold,	23	$3\frac{1}{2}$	0	18	10	18,080.
Lead			0	1	14	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,765.
Lead			0	0	19	
Copper			0	0	19	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,312.
Copper			0	1	6	
Lead			0	0	8	
Gold,	23	$3\frac{1}{2}$	0	18	10	17,032.
Copper			0	1	10	
Lead			0	0	4	
Gold,	23	$3\frac{1}{2}$	0	18	10	16,627.
Copper			0	1	$13\frac{1}{2}$	
Lead			0	0	$0\frac{1}{2}$	

TABLE I. *(continued.)*

Gold variously alloyed.					Specific Gravity.
	car. grs.	oz.	dts.	grs.	
Gold,	23 $3\frac{1}{2}$	0	18	10	17,039.
Copper		0	1	$13\frac{3}{4}$	
Lead		0	0	$0\frac{1}{4}$	
Gold,	23 $3\frac{1}{2}$	0	18	10	18,038.
Bismuth		0	1	14	
Gold,	23 $3\frac{1}{2}$	0	18	10	17,302.
Copper		0	1	6	
Bismuth		0	0	8	
Gold,	23 $3\frac{1}{2}$	0	18	10	16,846.
Copper		0	1	10	
Bismuth		0	0	4	
Gold,	23 $3\frac{1}{2}$	0	18	10	16,780.
Copper		0	1	$13\frac{1}{2}$	
Bismuth		0	0	$0\frac{1}{2}$	
Gold,	23 $3\frac{1}{2}$	0	18	10	17,095.
Copper		0	1	$13\frac{3}{4}$	
Bismuth		0	0	$0\frac{1}{4}$	
Gold,	23 $3\frac{1}{2}$	0	18	10	16,937.
Zinc		0	1	14	
Gold,	23 $3\frac{1}{2}$	0	18	10	17,175.
Zinc		0	0	19	
Copper		0	0	19	
Gold,	23 $3\frac{1}{2}$	0	18	10	17,402.*
Copper		0	1	6	
Zinc		0	0	8	

* The chief part of the zinc appeared to have been volatilized.

TABLE I. *(continued.)*

Gold variously alloyed.						Specific Gravity.
	car.	grs.	oz.	dts.	grs.	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Fine brass			0	1	14	17,293.
Gold,	23	$3\frac{1}{2}$	0	18	10	
Brass			0	0	19	16,914.
Copper			0	0	19	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Cobalt			0	1	14	17,112.
Gold,	23	$3\frac{1}{2}$	0	18	10	
Cobalt			0	0	19	17,255.
Copper			0	0	19	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Copper			0	1	6	17,341.
Cobalt			0	0	8	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Copper			0	1	10	17,286.
Cobalt			0	0	4	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Nickel			0	1	14	17,068.
Gold,	23	$3\frac{1}{2}$	0	18	10	
Nickel			0	0	19	17,298.
Copper			0	0	19	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Copper			0	1	6	17,382.
Nickel			0	0	8	
Gold,	23	$3\frac{1}{2}$	0	18	10	
Copper			0	1	10	17,250.
Nickel			0	0	4	

TABLE I. *(continued.)*

Gold variously alloyed.				Specific Gravity.
	oz.	dts.	grs.	
Gold, 23 car. $3\frac{1}{2}$ grs.	0	18	10	16,929.
Antimony	0	1	14	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,147.
Antimony	0	0	19	
Copper	0	0	19	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,258.
Copper	0	1	6	
Antimony	0	0	8	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,169.*
Copper	0	1	10	
Antimony	0	0	4	
Gold, 23 $3\frac{1}{2}$	0	18	10	17,073.
Copper	0	1	$13\frac{3}{4}$	
Antimony	0	0	$0\frac{1}{4}$	

The preceding experiments afford some remarkable results, produced in the specific gravity of gold, by the addition of certain metallic substances in various proportions; but, as these results are sufficiently pointed out in the subsequent pages, it would be superfluous to enter into a recapitulation of the whole.

The effects, however, produced upon gold by lead and bismuth, are peculiarly worthy of notice, not only on account of the alterations in specific gravity, but also from the remarkable similarity of the effects of these two metals, when employed as alloys in proportions relatively equal. This will appear more evident by the following comparative statement.

* 2.7 grs. of the antimony were lost by melting.

Gold alloyed with lead.*	dts.	grs.	Spec. Grav.	Gold alloyed with bismuth.†	dts.	grs.	Spec. Grav.
Gold	18	10	18,080.	Gold	18	10	18,038.
Lead	1	14		Bismuth	1	14	
Gold	18	10	17,765.	Gold	18	10	not examined.
Copper	0	19		Copper	0	19	
Lead	0	19		Bismuth	0	19	
Gold	18	10	17,312.	Gold	18	10	17,303.
Copper	1	6		Copper	1	6	
Lead	0	8		Bismuth	0	8	
Gold	18	10	17,032.	Gold	18	10	16,846.
Copper	1	10		Copper	1	10	
Lead	0	4		Bismuth	0	4	
Gold	18	10	16,627.	Gold	18	10	16,780.
Copper	1	$13\frac{1}{2}$		Copper	1	$13\frac{1}{2}$	
Lead	0	$0\frac{1}{2}$		Bismuth	0	$0\frac{1}{2}$	
Gold	18	10	17,039.	Gold	18	10	17,095.
Copper	1	$13\frac{3}{4}$		Copper	1	$13\frac{3}{4}$	
Lead	0	$0\frac{1}{4}$		Bismuth	0	$0\frac{1}{4}$	

* Specific gravity of the lead 11,352.

† Specific gravity of the bismuth 9,822.

Although the specific gravities of lead and of bismuth are so different, yet the effects which these metals produce upon the specific gravity of gold, according to their relative proportions, must appear very similar, to every one who examines the foregoing Table. Moreover, the quality of the gold thus made standard by different proportions of lead and bismuth, corresponded with the alterations of specific gravity; for, in the first experiments, or those in which lead in the one case and bismuth in the other formed the whole of the alloy, the gold was found to be brittle, like glass, and shewed a fine grained

fracture, which had a porcellaneous appearance; but, in the subsequent experiments, in proportion as the specific gravity was reduced, the grain of the fracture became coarser; and, in the IVth *Experiment*, the porcellaneous or earthy appearance of the fracture began to give place to a certain degree of metallic lustre, which was increased in the Vth *Experiment;* at the same time, the alloyed gold, in both cases, became remarkably coarse-grained and spongy.

The specific gravity was then found to be at the lowest degree; for, in the VIth or last *Experiment*, when only $\frac{1}{4}$ of a grain of lead, or of bismuth, was present, the grain became compact, with complete metallic lustre; and the specific gravity was so much increased, that when lead was employed, the difference between the Vth and VIth *Experiments* was 0,412; and, when bismuth was present, the difference was 0,315.

From these and other experiments, I am induced to believe, that, in general, the specific gravity of gold alloyed with different metals, is not only very different to what it ought to be according to calculations made on the relative proportions and specific gravity of the alloy, but that it is also subject to many variations, partly occasioned by peculiar effects produced by certain proportions of some of the metals, and partly by effects peculiar to certain compound alloys; so that, by the proportions of certain metals, and by the combination of these with others, an immense complicated series of alterations in specific gravity are produced, which as yet do not appear to have been investigated, by those philosophers who have written concerning the specific gravity of metals.

The specific gravity of standard gold being found by the preceding experiments to be so extremely variable, according to the nature and quantity of the metals which were employed singly or conjointly as alloys, the following Table has been added, to show the comparative degrees of expansion and contraction which took place, in consequence of these combinations.

TABLE II.

Metals.	Specific gravity.	Weight.	Bulk before combination, in grains of water.		Bulk after combination.	Expansion.	Contraction.	Specific gravity of the mass.
		grains.						
Gold - Silver -	19,172 10,474	442 38	23,05 3,63	26,68	26,78	,10	—	17,927
Gold - Silver - Copper -	19,172 10,474 8,895	442 19 19	23,05 1,81 2,14	27,00	27,67	,67	—	17,344
Gold - Copper -	19,172 8,895	442 38	23,05 4,27	27,32	27,98	,66	—	17,157
Gold - Iron -	19,172 7,700	442 38	23,05 4,94	27,99	28,43	,44	—	16,885
Gold - Iron - Copper -	19,172 7,700 8,895	442 19 19	23,05 2,47 2,14	27,66	28,03	,37	—	17,125
Gold - Tin - -	19,172 7,291	442 38	23,05 5,21	28,26	27,73	—	,53	17,307
Gold - Tin - Copper -	19,172 7,291 8,895	442 19 19	23,05 2,61 2,14	27,80	27,78	—	,02	17,278
Gold - Copper - Tin -	19,172 8,895 7,291	442 30 8	23,05 3,37 1,10	27,52	27,66	,14	—	17,352
Gold - Lead -	19,172 11,352	442 38	23,05 3,35	26,40	26,54	,14	—	18,080

TABLE II. *(continued.)*

Metals	Specific gravity.	Weight.	Bulk before combination, in grains of water.		Bulk after combination.	Expansion.	Contraction.	Specific gravity of the mass.
		grains.						
Gold - Lead - Copper -	19,172 11,352 8,895	442 19 19	23,05 1,67 2,14	26,86	27,02	,16	—	17,765
Gold - Copper - Lead -	19,172 8,895 11,352	442 30 8	23,05 3,37 ,70	27,12	27,73	,61	—	17,312
Gold - Copper - Lead -	19,172 8,895 11,352	442 34 4	23,05 3,82 ,35	27,22	28,18	,96	—	17,032
Gold - Copper - Lead -	19,172 8,895 11,352	442 37,50 0,50	23,05 4,22 ,04	27,31	28,87	1,56	—	16,627
Gold - Copper - Lead -	19,172 8,895 11,352	442 37,75 0,25	23,05 4,24 ,02	27,31	28,17	0,86	—	17,039
Gold - Bismuth	19,172 9,822	442 38	23,05 3,87	26,92	26,61	—	,31	18,038
Gold - Copper - Bismuth	19,172 8,895 9,822	442 30 8	23,05 3,37 ,82	27,24	27,74	,50	—	17,302
Gold - Copper - Bismuth -	19,172 8,895 9,822	442 34 4	23,05 3,82 ,41	27,28	28,49	1,21	—	16,846
Gold - Copper - Bismuth -	19,172 8,895 9,822	442 37,50 0,50	23,05 4,22 ,05	27,32	28,61	1,29	—	16,780
Gold - Copper - Bismuth -	19,172 8,895 9,822	442 37,75 0,25	23,05 4,24 ,03	27,32	28,07	,75	—	17,095
Gold - Zinc -	19,172 7,065	442 38	23,05 5,38	28,43	28,34	—	,09	16,937
Gold - Zinc - Copper -	19,172 7,065 8,895	442 19 19	23,05 2,69 2,14	27,88	27,95	,07	—	17,175

TABLE II. *(continued.)*

Metals.	Specific gravity.	Weight.	Bulk before combination, in grains of water.		Bulk after combination.	Expansion.	Contraction.	Specific gravity of the mass.
		grains						
Gold - Copper - Zinc -	19,172 8,895 7,065	442 30 8	23,05 3,37 1,13	27,55	27,58	,03	—	17,402
Gold - Cobalt -	19,172 7,645	442 38	23,05 4,97	28,02	28,05	,03	—	17,112
Gold - Cobalt - Copper -	19,172 7,645 8,895	442 19 19	23,05 2,48 2,14	27,67	27,82	,15	—	17,255
Gold - Copper - Cobalt -	19,172 8,895 7,645	442 30 8	23,05 3,37 1,05	27,47	27,68	,21	—	17,341
Gold - Copper - Cobalt -	19,172 8,895 7,645	442 34 4	23,05 3,82 ,52	27,39	27,77	,38	—	17,286
Gold - Nickel -	19,172 7,807	442 38	23,05 4,87	27,92	28,12	,20	—	17,068
Gold - Nickel - Copper -	19,172 7,807 8,895	442 19 19	23,05 2,43 2,14	27,62	27,75	,13	—	17,298
Gold - Copper - Nickel -	19,172 8,895 7,807	442 30 8	23,05 3,37 1,03	27,45	27,61	,16	—	17,382
Gold - Copper - Nickel -	19,172 8,895 7,807	442 34 4	23,05 3,82 ,51	27,38	27,83	,45	—	17,250
Gold - Antimony	19,172 6,712	442 38	23,05 5,66	28,71	28,35	—	,36	16,929
Gold - Antimony Copper -	19,172 6,712 8,895	442 19 19	23,05 2,83 2,14	28,02	27,99	—	,03	17,147
Gold - Copper - Antimony	19,172 8,895 6,712	442 30 8	23,05 3,37 1,19	27,61	27,81	,20	—	17,258

TABLE II. *(continued.)*

Metals.	Specific gravity.	Weight.	Bulk before combination, in grains of water.		Bulk after combination.	Expansion.	Contraction.	Specific gravity of the mass.
		grains.						
Gold -	19,172	442	23,05					
Copper -	8,895	34	3,82	27,47	27,94	,47	—	17,169
Antimony	6,712	4	,60					
Gold -	19,172	442	23,05					
Copper -	8,895	37,75	4,24	27,33	28,11	,78	—	17,073
Antimony	6,712	0,25	,04					

Although the experiments upon which I have formed the preceding Table were made with considerable care and attention, yet it certainly would not be right to suppose the degrees of expansion or contraction to be rigidly and exactly determined in every fractional part; for, besides the almost impossibility of totally preventing the escape of some part of the more volatile metals, even a variation in the degree of heat during melting, as well as in the mode of cooling, must make some difference, for which an allowance ought to be made; but these unavoidable inaccuracies, do not prevent the more general and essential effects from being ascertained.

Very little alteration appears to have been produced by alloying gold with $\frac{1}{12}$ of pure silver;* for the alloyed mass only differed from the natural bulk of the two metals by ,10; and this accords with former observations upon the effects which these metals produce on each other.

But, in the next case, which consisted of gold alloyed with

* In this and every other case, when the proportion of alloy was estimated, an allowance has been made for the deficiency in the quality of the gold, amounting to half a carat grain.

equal parts of silver and copper, the expansion amounted to ,67; which is the more remarkable, as, in the subsequent article, copper being employed singly, produced only an expansion of ,66. It appears, therefore, that the compound alloy of silver and copper, being added in the proportion of $\frac{1}{12}$ to gold, causes a degree of expansion superior to that produced by copper, although it might be previously imagined, that the silver would have checked or diminished the expansive property of the copper.

$\frac{1}{12}$ of iron appears to have caused an expansion rather inferior to that of copper; but an alloy composed of equal parts of iron and copper, produced an expansion less than the former. This effect seems also to be peculiar to this compound alloy; for, according to the effects which copper was found singly to produce upon gold, the compound alloy of iron and copper ought to have produced an expansion superior to that caused by iron alone.

A considerable contraction was caused when $\frac{1}{12}$ of tin was added to gold; but, as an attempt had been made to pass the mass between rollers, before the specific gravity was taken, the contraction must not be estimated at so much as ,53.

When gold was alloyed with equal parts of tin and copper, the contraction was found to be only ,02; but, in the next case, when the copper amounted to 30 grains, and the tin only to 8, an expansion took place, equal to ,14.

$\frac{1}{12}$ of lead produced an expansion equal to ,14; but, from the similarity of all the other effects of lead to those of bismuth, I am inclined to believe that lead, in some proportion greater than $\frac{1}{12}$, would produce contraction. In all the instances, however, stated in the Table, expansion was observed; and, when lead was in the proportion of 4 grains to 34 of copper, or of

half a grain to $37\frac{1}{2}$ of the same metal, then a very remarkable expansion took place, which seemed to be a peculiar effect of this compound alloy; for, in the subsequent case, when the lead was reduced to $\frac{1}{4}$ of a grain, the degree of expansion was much less.

Bismuth, in its various properties, as I have several times had occasion to observe, very much resembles lead, in respect to the effects which it produces upon gold, excepting, that when employed singly, and in the proportion of $\frac{1}{12}$, it occasioned a contraction equal to ,31. But, in smaller quantities, and in conjunction with copper, it produced expansion, which became very considerable, when bismuth was added in the proportion of 4 grains, or of half a grain, per ounce; so that what has been already said concerning lead may here be repeated.

$\frac{1}{12}$ of zinc caused the mass to contract ,09; but the volatility of this metal renders the results very uncertain. In the last article, nearly the whole of the 8 grains of zinc were volatilized.

It is not necessary to make any remarks on the effects produced by cobalt and nickel upon gold; and, in respect to antimony, we may observe, that contraction was produced in the two first cases, but expansion in all the others. Indeed, from a general view of the Table it appears, that those metals which most readily render gold brittle, are those which have the greatest tendency to produce contraction, when added to gold in certain proportions.

In some cases, the degree of expansion seems to increase with the proportion of copper; but then it must be observed, that this increase of expansion is frequently much more considerable

than that which ought to be produced, supposing this effect depended only upon the quantity of copper; it may therefore be inferred, that the properties of a compound metal are peculiar to itself, and are in general different from the mean of the properties of the several metals employed to form the compound.

The results stated in the foregoing Table, seem to indicate, that the assertions of many respectable authors, concerning the density of alloyed metals, should not be understood in an absolute or unqualified sense.

Mr. BRISSON, in his valuable work entitled *Pèsanteur specifique des Corps*, has observed, that a mutual penetration takes place, when eleven parts of gold are alloyed with one of copper; and, in consequence of this, that he found the specific gravity of gold alloyed with $\frac{1}{12}$ of copper to be 17,486; although, if this mutual penetration of the two metals had not happened, the specific gravity ought to have been 17,153; but, in the course of the present experiments, the reverse of this has been observed; for, instead of any mutual penetration of these metals, a very notable degree of expansion in the alloyed mass has been remarked.

When 442 grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, (the specific gravity of which was 19,172,) were alloyed with 38 grains of fine copper, of the specific gravity of 8,895, the mass was found to be of a specific gravity equal to 17,157; and, as the bulk of this alloyed mass amounted to 27,98, while the natural bulk of the two metals before combination amounted only to 27,32, there was consequently an expansion of the alloyed mass, equal to ,66. These calculations were made upon an intire ingot, weighing two ounces Troy, or 960 grains; which mode appeared

to me to be more accurate, than if the experiments had been made upon part of a large mass or ingot. In the latter case there are many sources of error, which either have been or will be noticed in the present Paper; and the observations made upon them apply to the subject under immediate examination, as well as to the specific gravity of compound or alloyed metals in general.

If Mr. BRISSON made his experiment upon part of a large bar or ingot, (which probably was the case,) it will not be difficult to conceive the reason why he found the specific gravity to be 17,486. For, the unequal diffusion of the alloy, the quantity of the metal, with the *nature*, *form*, and *position*, of the mould, will always produce variations in specific gravity.

In some experiments, when copper was present in rather a less proportion than the above, still a very conspicuous degree of expansion prevailed, even in that part of the mass which was subjected to the pressure of a considerable quantity of superincumbent metal, and even when the whole was cast in a mould of iron, which, from repeated experiments, I have found to be unfavourable to the expansion of metals. As a proof of this, I shall state an experiment which will again be found in a subsequent part of this Paper, but which may here be anticipated with propriety, as it tends to elucidate the present subject.

Experiment.

A quantity of gold, 23 car. $3\frac{1}{2}$ grs. fine, was alloyed with fine Swedish copper, in such a proportion as to form an uniform mass, which, by assays made upon both extremities, proved to be 8 Troy grains in the pound better than standard.

Two pounds of this alloyed gold were cast in a mould of

iron, by which a bar was formed, nearly 12 inches in length, one inch in breadth, and one quarter of an inch in thickness. Every possible precaution had been taken, to mix and diffuse the copper uniformly throughout the gold; and the assays which were made subsequent to the casting, fully proved that the mixture was perfect. When, however, the specific gravity of the two extremities, or of the top and bottom ends of the bar, was examined, it appeared, that the specific gravity of the upper end was 17,035, while that of the lower end was 17,364. So that, although the quality of the bar was perfectly equal in every part, yet, by the pressure of the superincumbent metal, the lower extremity, or that which was formed in the bottom of the mould, had acquired a very superior degree of density.

Now, from the foregoing Table it appears, that the bulk of 442 grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, is very nearly 23,05, and that the bulk of the fine Swedish copper employed in these experiments is, for 38 grains, equal to 4,27; consequently, the total bulk of these two metals, before combination, amounts to 27,32. Moreover, when these metals were combined, then the bulk of 480 grains of this standard gold was 27,98; so that an expansion equal to ,66 had taken place, in consequence of the combination of 442 grains of the gold with 38 of the copper. In order to compare this result with the bar abovementioned, it must be first remembered, that the quality of the latter was, throughout, 8 grains better than standard; and, consequently, 480 grains of this gold, consisted of 442,66 grs. of fine gold, and 37,34 grs. of copper. The bulk, therefore, of the 442,66 grs. of gold amounts to 23,08, while that of the 37,34 grs. of copper is 4,19; which, added together, gives 27,27 for the total bulk of 480 grains before combination. But, when

this had been effected, and the bar had been cast as already mentioned, then the bulk of the upper extremity was found to be 28,18, while that of the lower end was only 27,64. The difference, therefore, between 27,27 and 28,18, shows, that an expansion equal to ,91 had taken place in the upper end of the bar; and the difference between 27,27 and 27,64, also shews, that an expansion equal only to ,37 had taken place in the inferior extremity; and that thus a difference of ,54, in the expansion of the two extremities, had been produced merely by the pressure of the superincumbent metal. Had it not been for this circumstance, there is reason to believe, that the general expansion of the whole mass would have been nearly the same as that of the standard gold mentioned in the Table, namely, ,66; for the expansion of the upper end of the bar being ,91, and that of the lower end being ,37, the mean consequently must be ,64, which (taking into consideration the small difference in the quality of the two kinds of alloyed gold) may be regarded as a very near approximation to the statement in the Table.

It will now be proper to notice other causes, which more or less influence the specific gravity of what is called standard gold.

The most frequent cause of variations, in the specific gravity of gold made standard by silver or copper, is the unequal diffusion of the alloy throughout the mass of gold; for an exact distribution of the alloy is not so easily made as may be imagined, especially when a large quantity of gold is to be alloyed.

In Mints, this difficulty has however been considered, and an allowance has been made for it, which is called the Remedy for the Master of the Mint.

According to this regulation, when the trial of the Pix, as it

is called, takes place before the Lord Chancellor, the Lords Commissioners of the Treasury, &c. &c. &c. the Master of the Mint is held excusable, if the imperfection or deficiency of the coin, in the aggregate, is less than the sixth part of a carat, equal to 40 grains of fine gold, in the pound of standard, or the 132d part of the value.

When it is considered, that the extreme accuracy of philosophical experiments cannot easily be introduced into such establishments as mints, where the work is carried on upon a large scale, some latitude may with reason be expected, and granted, especially as a perfectly exact mixture of the alloy is attended with difficulty.

In HELLOT'S French translation of SCHLUTTER'S work, entitled *Essais des Mines et des Metaux*, p. 276, the following experiment is mentioned, in order to prove the frequent unequal mixture of gold with another metal, such as silver.

"A quantity of silver, amounting to upwards of twenty "pounds, and containing about a 56th part of gold, was melted "in a crucible, and poured into cold water, in order that it might "be granulated: by dipping, at different times, an iron ladle "into the water under the stream of metal, parts of the first, "second, and third running were separately received; and, "being assayed, were all found to differ in their content of gold."

Dr. LEWIS, who has noticed this experiment, also describes another made by Mr. HOMBERG, which is related in the Memoirs of the Academy of Paris, for the year 1713.

"Equal parts of gold and silver, melted together, and reduced "into fine grains, were put into a crucible, with a mixture of "about equal parts of decrepitated sea salt and rough nitre "under them: the crucible being kept in a small fire in a wind

"furnace for about a quarter of an hour, and then suffered to "cool, was broken; the gold was then found in one lump at "the bottom, and the silver above it, in two pieces, with some "grains enveloped in the salts, which had not been intirely "melted. The silver was perfectly pure, and without the least "mixture of gold; but the gold retained about one-sixth part "of silver."

He repeated the experiment, with different mixtures of the two metals, and found the silver to be always free from gold, but that the gold retained a little of the silver, except in two instances, in which this was also pure. Mr. Homberg observes, that "unless the gold and silver are nearly in equal "quantities, the separation does not succeed; and that the only "nicety in the process consists in hitting the due point of fusion; "for, if the fire is too long continued, or the mixt made to flow "thin, the two metals, after they have parted from one another, "mingle again together." Lewis's Phil. Comm. of Arts, p. 86.

From these experiments it appears, that the equal distribution and mixture of two metals, such as gold and silver, is by no means very easy to be made, without certain precautions; and also, that when they have been completely mixed, if they are kept in fusion under certain circumstances, a separation, more or less perfect, sometimes takes place. This separation appears to be according to the relative affinities and specific gravities of the two metals, and is the soonest effected when the metals have not been perfectly mixed.*

Soon after the commencement of the experiments at the Mint,

* Some compound metals may perhaps be mere mechanical mixtures; but I am inclined to believe, that by much the greatest number are true chemical combinations; and consequently, when these last have been properly formed, a separation of the component metals, by the means abovementioned, can seldom if ever be effected.

I was desirous to examine the specific gravity of some bars of gold, which had been made standard by the addition of various kinds of copper; and, as every usual precaution had been taken to mix the alloy properly with the gold, the pieces which were to be hydrostatically weighed were taken from the ends of the bars, without any discrimination whether the pieces were cut from the end of the bars which, when cast, had been formed near the mouth of the mould, or from that end which had been formed at the bottom. The following were the results.

		Specific gravity.
1.	Gold made standard by the best Swedish copper, the bar being cast in a mould of iron -	17,372
2.	The same bar melted again, and cast in sand -	17,312
3.	Gold made standard by common Swedish copper, cast in sand - - - -	16,225
4.	Gold made standard by Swedish dollar copper, cast in sand - - - -	16,977
5.	Gold made standard by British copper, cast in iron	17,281
6.	The same, cast in sand - - -	16,994
7.	Gold made standard with another sample of British copper, cast in sand - -	16,979

From these experiments it was evident, that when the same metal was cast in iron and in sand, a difference was to be observed in the specific gravity, which was always the most considerable when moulds of iron were employed; but, allowing that this might have operated at certain times, yet so great a variation was discovered in other instances, that it was thought requisite to make a new series of experiments, in order to ascertain the cause; and, as there was reason to suspect, that part, at least, of this difference in specific gravity arose from an unequal

distribution of the alloy, two pieces were taken from the opposite extremities of each bar, and were examined as follows.

	Specific gravity.	
	Upper end.	Lower end.
1. Gold made standard by silver -	18,273	17,186
2. Gold made standard by equal parts of silver and copper - - -	18,062	16,659
3. Gold made standard by copper -	18,492	16,680
4. Gold made standard by lead -	18,124	18,037
5. Gold made standard by equal parts of copper and iron - - -	17,068	16,924
6. Gold made standard by an alloy composed of $\frac{3}{4}$ copper and $\frac{1}{4}$ of tin -	17,551	16,747
7. Gold made standard by antimony -	17,121	16,707

Each of the bars weighed two pounds Troy; they were one inch broad, and $\frac{1}{4}$ of an inch in thickness; and were cast in a mould of iron.

From these experiments it appeared, that the upper extremities of these bars, or those which had been formed at or near the mouth of the mould, were uniformly of greater specific gravity than the opposite ends of the same bars, or those which had been formed in the bottom of the mould; and that the smallest variation in the specific gravity of the two ends of a bar, was in that which consisted of gold alloyed with lead.

The above mixtures were made with the usual precautions, such as rapid stirring, and pouring; but, nevertheless, it seemed that the alloy had never been completely and uniformly distributed throughout the mass of gold; or, if it really had been well diffused and mixed, that it subsequently (although in a very short time) had again separated, according to its relative

specific gravity to that of gold. Therefore, as the upper end of each bar was uniformly of a much greater specific gravity than the opposite extremity, and as the metal was speedily congealed in the mould, and as the contents of each crucible, when poured, occupied the mould in an inverted order, (the metal at the bottom of the crucible being that which was last poured, and consequently being that which formed the upper extremity of the bar,) there was much reason to believe that the alloy was not equally distributed, and that the melted mass, when in the crucible, varied in quality, so that the lower part consisted of gold above standard, and the upper part, of gold inferior to standard; and, as but little alteration could take place when the metal was poured, this unequal quality remained, although inverted in respect to situation.

In consequence of these experiments, it became necessary to contrast them with comparative assays.

Several of these were therefore made; but I shall only mention such as are immediately requisite to determine the question. It is proper, however, to remark, that the upper extremities of the bars which have been mentioned, were all found to be better than standard, while the inferior extremities proved to be worse. But the experiments to which I immediately allude are the following.

Experiment 1.

Twenty-two ounces two pennyweights and four grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, were alloyed with one ounce seventeen pennyweights and eighteen grains of copper. When the whole was completely melted, it was rapidly stirred, and was then suffered to continue in fusion during half an hour; after which, it was poured into a mould of iron.

The rough end of the bar, next the mouth of the mould, was cut off, and then three pieces were taken, viz. one from the upper extremity, another from the middle, and a third from the bottom.

The specific gravity of these three pieces was ascertained; and they were then assayed by Mr. BINGLEY, his Majesty's Assay Master at the Mint, who reported them as follows.

	Specific gravity.	Quality by assay.
1. Top -	18,141	Better than standard, $3\frac{1}{2}$ carat grs.* = 210 Troy grains.
2. Middle -	17,043	Worse than standard, $1\frac{3}{4}$ carat grs. = 105 Troy grains.
3. Bottom	16,689	Worse than standard, $3\frac{3}{4}$ carat grs. = 225 Troy grains.

This experiment therefore proved, that as the upper extremity, or No. 1, was superior in specific gravity to the middle of the bar, or No. 2, so this last was superior to the bottom, or lower extremity, No. 3; in like manner, the quality of the gold was much better in No. 1 than in No. 2; and this also considerably surpassed the quality of the last, or No. 3.

But it was still uncertain, supposing the alloy to have been perfectly mixed, whether it would readily become partly separated from the gold, so as to leave the mass thus of different qualities.

To determine this, the next experiment was made.

* One carat grain is equal to 60 Troy grains.

Experiment II.

Eleven ounces one pennyweight and two grains of gold, 23 car. $3\frac{1}{2}$ grs. fine, were alloyed with nineteen pennyweights and six grains of copper; the whole being well melted, was stirred with a large earthen stirrer; and, in order the better to mix the alloy with the gold, the melted metal was poured alternately into two red-hot crucibles, after which, it was cast in the mould of iron. The rough end of the bar was cut off, and a piece was then taken from each extremity.

The specific gravity of the upper end was - 17,035
And that of the lower end was - - 17,364.

So that, according to this experiment, the bottom end of the bar possessed the greatest specific gravity, contrary to the results of the former experiments.

By an assay of each piece, made by Mr. BINGLEY, it however appeared, that this difference in specific gravity was not caused by any unequal quality of the gold, for the proportion of alloy in the two pieces was found to be precisely the same; the alloy had therefore been uniformly mixed.

	Specific gravity.	Quality by assay.
1. Top	17,035	Better than standard, by 8 grains Troy.
2. Bottom	17,364	Better than standard, by 8 grains Troy.

It now remained, therefore, to examine whether the copper alloy, which was thus regularly distributed throughout the mass, could again be induced to separate by a subsequent fusion.

Experiment III.

The bar which had been made in the preceding experiment, was again melted, and was kept in complete fusion during half

an hour, without being stirred or agitated; it was then cast as before.

The two extremities, being separated, afforded the following results.

		Spec. gravity.		Quality by assay.
1.	Top	17,203	-	Better than standard, by 10 grains Troy.
2.	Bottom	17,387	-	Better than standard, by 10 grains Troy.

This last bar was, therefore, throughout of an equal quality; although it appeared that, by this second fusion, the whole mass was become finer, by two Troy grains, than it was in the former experiment; and the specific gravity of both ends was also become more considerable.

In these two last experiments, the specific gravity of the bars was the greatest at the bottom; and as by the assays it was proved, that each bar was of an uniform quality, it may be inferred, that when a bar of metal is cast in, or nearly in, a vertical position, a difference in the density of the mass takes place, independent of any change in the quality of the mixture, and that the greatest density prevails in the lower part of the column, or in that which suffers the greatest pressure from the superincumbent metal. It also follows, that this effect is subject to be modified by the quality and specific gravity of the metal, by the more or less vertical position of the mould, by the quantity of metal which is cast, and especially by the length of the bar, or height of the metallic column.

There cannot be any doubt but that the same causes operated in those experiments which afforded results so precisely opposite to these last, in respect to the relative specific gravities of the extremities of the bars; but then, the effect in question was much more than compensated by the unequal distribution of

the alloy, which predominated in the upper part of the mass when in the crucible, and consequently was the first which entered and filled the lower part of the mould, so that the finer and more heavy gold, at the bottom of the crucible, was that which formed the upper part of the bar; and it must be obvious, that the congelation was too rapid in the mould, to allow any very material change to take place after the metal was poured.

The foregoing facts being considered, it is possible to conceive, that a bar of alloyed gold may be throughout of equal specific gravity, and nevertheless not be of an uniform value or quality; for the finer quality of the upper extremity, when not considerable, may at times be compensated by the superior density of the bottom; but such effects can only take place within a very limited sphere.

Exclusive of the causes lately enumerated, which occasion variations more or less considerable in the specific gravity of metals, there is another, which, I believe, has never been noticed; it is true that its effects, when compared with those already mentioned, are but small; but still it appears proper that it should be taken into consideration, in the course of the present investigation. Long continued friction, is the cause to which I now allude; for I have always found, that it produced a diminution in the specific gravity of those pieces of metal which had been subjected to it, as the following experiments will prove.

Experiment I.

In this experiment, forty-two pieces of gold, differently alloyed, and of the diameter of a guinea, were taken in the following order.

1. Gold of 23 car. $3\frac{3}{4}$ grs. fine - - - 6 pieces.
2. Gold alloyed with silver - - - 6 pieces.
3. Gold alloyed with silver and copper - 6 pieces.
4. Gold alloyed with copper - - - 6 pieces.
5. Gold alloyed with copper and iron - - 6 pieces.
6. Gold alloyed with $\frac{3}{4}$ of copper and $\frac{1}{4}$ of tin - 6 pieces.
7. Gold alloyed with an equal part of copper - 6 pieces.

The specific gravity of each of the foregoing series of six pieces was then taken, with every possible precaution; and afterwards the pieces were fixed in a machine, so that three of each series were opposed to the other three which were of a similar quality. The machine was then put in motion; and these pieces were made to rub against each other for a considerable time, or till 200300 revolutions had been performed; after which, the pieces were removed, and the specific gravity of each series was again ascertained.

The following comparative statement will show, that a very evident diminution of the original specific gravity had taken place, in consequence of this long continued friction.

Quality.	Specific gravity before friction.	Specific gravity after friction.
1. Gold of 23 car. $3\frac{3}{4}$ grs. fine -	19,277	19,171
2. Gold alloyed with silver -	18,092	18,055
3. Gold alloyed with silver and copper - - -	18,184	18,182
4. Gold alloyed with copper -	18,053	18,014
5. Gold alloyed with copper and iron - - - -	17,151	17,095
6. Gold alloyed with copper and tin - - - -	17,607	17,581
7. Gold and copper, in equal parts	12,142	12,139

The proportion of gold in the foregoing pieces exceeded, in general, the standard quantity; but that circumstance did not interfere with the principal object of these experiments, which will also be corroborated by the result of the subsequent experiment.

Experiment II.

Twelve pieces of fine copper, similar in size to those of gold which were employed in the former experiment, were weighed hydrostatically, altogether, and were afterwards placed in the machine, so that six were made to rub against six. After 22200 revolutions, they were taken out, and their specific gravity was again accurately examined.

A very apparent diminution was found to be the result, for the specific gravity was,

Before friction.	After friction.
8,785	8,283.

Considering, therefore, that this diminution of specific gravity was found in each of the foregoing series, as well as in the

present experiment, after the pieces had been subjected to long continued friction, there cannot be any doubt but that this is a general effect, which probably arises from the pieces having suffered expansion, in consequence of heat generated during the friction; and, (similar to what has been observed in pyrometrical experiments,) that these pieces of metal did not, upon the cessation of friction, return precisely to their original size and specific gravity.

Among the other less powerful causes which produce some alteration in the specific gravity of gold, the processes of rolling, and of annealing, may also be enumerated; for, in the course of these experiments, I have always found, that the specific gravity of the bars, &c. was in a small degree increased by rolling, and that the contrary effect was produced by annealing.

The specific gravity of gold, 23 car. $3\frac{3}{4}$ grs. fine, when rolled and stamped without being annealed, I found to be 19,277; but, when the same was annealed, the specific gravity was 19,231.

I am, however, inclined to believe, that annealing had reduced the specific gravity to much less than is here stated; and that the subsequent operation of stamping had, in some measure, compensated the effects of annealing. For, it may be recollected, that in the experiments lately mentioned, it was proved, that the specific gravity of the pieces which had not been annealed, was reduced, by long continued friction, from 19,277 to 19,171; an effect surpassing that which resulted from annealing by ,060 (19,231 — 19,171 = ,060); and, if heat was the cause, the reverse might have been expected, inasmuch as the annealing heat exceeded that which was produced by friction; but,

as this was not the case, I am induced to be of opinion, that the specific gravity was again increased, by the subsequent stamping of the annealed pieces.

In addition, therefore, to those causes of variation in specific gravity which are the immediate consequences of hydrostatical operations, such as, the different height of the column of water, and the changes of temperature to which it is exposed during the experiments, the following, as far as they concern metallic substances, may be enumerated.

1. Imperfections in the interior of the mass, which are produced during the processes of melting and casting.

2. The difference of density in parts of the same mass, resulting from the quality and quantity of the metal, from the nature of the mould, from the more or less vertical position of it, and from the height of the column or bar of metal which is cast.

3. The unequal distribution of the metal, or metals, employed as an alloy, throughout the mass intended to be alloyed.

4. The peculiar effects which certain metals produce, when used singly or conjointly as alloys, and which are very different from the results of calculation.*

5. Heat, whether produced by friction or excited in any other manner.

* There can be no doubt but that the effects of compound alloys are, in general, very different from those of each metal separately considered; and that such metallic combinations or compound alloys, like neutral salts, and many other compounds, have peculiar properties, which act variously upon the metals to which these compound alloys are added. A great number of accurate experiments are, however, requisite to elucidate a question so intricate.

It may here be also observed, that the peculiar properties of compound alloys, prove them to be real chemical combinations.

As, therefore, the specific gravity of metals is liable to be influenced by such a variety of causes, it is almost in vain to expect absolute precision, in the results of experiments made by different persons; but, at the same time, it may be observed, that by proper care and attention to the above circumstances, a degree of accuracy may be attained, sufficient to answer almost every useful purpose, although, from what has been said, it must appear improper to form opinions upon small fractional variations. By the experiments which I made, with every possible precaution, upon separate and intire ingots of gold, reduced to standard by silver, by silver and copper, and by copper alone, when cast in an iron mould like a cupel, it appeared, that the specific gravity of each of these kinds of standard gold is as follows.

Gold made standard by silver - -	17,927
Gold made standard by silver and copper -	17,344
Gold made standard by copper - -	17,157.

Now, as our gold coin commonly contains silver as part of the alloy, and as at different times this proportion of silver must have been various, and even considerable, particularly when the gold of Portugal, which is alloyed with silver, was brought to the Mint, it naturally follows that, exclusive of the many other causes of variation which have lately been enumerated, the specific gravity of our standard gold must occasionally be different, according to the relative proportions of silver and copper which compose the alloy;* and, as the specific gravity of gold made standard by silver is, in the ingot cast under the above circum-

* The first guineas which were coined, or those of CHARLES II. and JAMES II. were generally alloyed with standard silver; but the coins of the subsequent reigns have been alloyed with copper, added to compensate the deficiency of alloy, or of silver in the gold.

stances, 17,927, while that of gold made standard by copper is only 17,157, so, according to the relative proportions of these two metals, when united in the alloy, the specific gravity of the standard gold may vary between the two extremes of 17,927 and 17,157, although the real quality or value of the standard gold remains unchanged; and indeed, when some allowance is also made for small variations arising from other causes, the range of the different specific gravities of gold made standard by silver and copper, may be considered as nearly extending from 18 to 17.

The following Table is intended to show the various Statements of different Authors, respecting the specific Gravity of fine and of standard Gold.

TABLE III.

Fine gold.	Specific grav.	Names of Authors.
Fine gold - -	19,640	WARD, COTES, MUSSCHENBROEK.
A medal, esteemed to be nearly fine gold -	19,636	CASWELL.
Fine gold - -	19,300 to 19,400	LEWIS.*

* Dr. LEWIS asserts, that when he had refined gold to the greatest degree of purity which he believed it capable of being brought to, and when the same had been well hammered, he, from many trials, found the specific gravity between 19,300 and 19,400. Phil. Comm. of Arts, p. 41.

From every circumstance, therefore, it may be concluded, that 19,640, which has been stated as the specific gravity of fine gold, by WARD, COTES, MUSSCHENBROEK, and others, is merely hypothetical.

TABLE III. *(continued.)*

Fine gold.	Specific grav.	Names of authors.
Gold of 24 car. hammered	19,361	BRISSON.
Gold of 23 car. $3\frac{3}{4}$ grs. stamped and rolled	19,277	HATCHETT.
Gold of 24 car. from an ingot - -	19,258	BRISSON.
Gold of 24 car. from another ingot - -	19,257	BRISSON.
Fine gold, hammered -	19,207	ELLICOT.
Gold in the ingot, said to be fine, and again refined with antimony -	19,184	ELLICOT.
Gold of 23 car. $3\frac{1}{2}$ grs. in the bar - - -	19,172	HATCHETT.
The ingot already mentioned by Mr. ELLICOT, before it was refined with antimony - -	19,161	ELLICOT.
A medal of the Royal Society, reported fine gold	19,158	GRAHAM.
A medal of Q. ELIZABETH	19,125	CASWELL.

TABLE III. *(continued.)*

Fine gold.	Specific grav.	Names of authors.
A medal of Queen MARY	19,100	CASWELL.*
Gold - -	19,081	FAHRENHEIT.
Aurum purum - -	19,000	BACON (ex Hyp.)
A coin of ALEXANDER	18,893	CASWELL.
Gold - - -	18,806	REYNOLDS.
Gold - - -	18,750	VILLALPANDUS.
Standard gold.	Specific grav.	Names of authors.
Gold of 22 car. or standard	18,888	CASWELL, WARD, COTES, and MUSSCHENBROEK.
An old JACOBUS, supposed to be the sceptered broad piece	18,375	HARRIS.
A five-guinea piece of King JAMES II. 1687 -	17,933	GRAHAM.
Guineas, 10, weighed together - - -	17,800	DAVIES.

* Dr. DAVIES observes, that these medals of Queen ELIZABETH and Queen MARY were undoubtedly the large Sovereigns of those queens, which were of the old standard of England, or of gold appointed to be of 23 car. $3\frac{1}{2}$ grs. fine. See Tables of specific Gravities, extracted from various Authors, with some Observations upon the same; by RICHARD DAVIES, M. D. Phil. Trans. Vol. XLV. page 416.

TABLE III. *(continued.)*

Standard gold.	Specific grav.	Names of authors.
Guineas, on a mean of seven trials upon those of different reigns - -	17,726	ELLICOT.
A guinea - -	17,629	BRISSON.*
A piece of gold-coin of the Commonwealth -	17,625	HARRIS.
Guineas, two new ones -	17,414	HAUKSBEE.
Gold made standard by silver, in the ingot -	17,927	HATCHETT.
Gold made standard by equal parts of silver and copper, in the ingot -	17,344	HATCHETT.
Gold made standard by fine Swedish copper, in the ingot	17,157	HATCHETT.

* From the whole of the experiments related in this Paper, it must be evident, that small fractional variations in the specific gravity of gold coin do not merit attention; it is not safe, therefore, to draw any general inference from a single experiment, made upon one piece, or even upon a small number of pieces.

Mr. BRISSON examined the specific gravity of a single guinea, which he found to be 17,629; and, as he had previously ascertained the specific gravity of the gold coin of France to be 17,647, he says, "this proves, (contrary to the received erroneous idea,) "that the specific gravity of the French gold coin is greater than that of England." *Pésanteur specifique des Corps,* p. 9.

But this conclusion of Mr. BRISSON cannot be admitted; for, even the different proportions of silver and copper in the alloy, (exclusive of other causes,) may produce variations in the specific gravity of standard gold, between 17,927 and 17,157.

However respectable the names of some of the foregoing authors may be, there is much reason to believe, that the specific gravity of fine gold, in the two first instances, has been too highly estimated; and, as to standard gold, there cannot be any doubt but that some error must have been the cause which induced CASWELL, WARD, COTES, and MUSSCHENBROEK, to rate it at 18,888; and HARRIS to state the specific gravity of the JACOBUS at 18,375.

What this error was, cannot now be determined; but, if the operations were accurately performed, and, considering the eminence of the persons concerned, this can scarcely be doubted, we must conclude that too small a proportion of alloy was present in both cases; for this appears to be very probable, from the general result of the whole of the preceding experiments.* Some such cause of error must have therefore prevailed, in the two first cases of standard gold contained in the foregoing Table; and it is absolutely necessary that this should be strongly pointed out, lest any one should fall into a mistaken notion, which has but too commonly been received in this country, and which has injuriously and unjustly been believed on the Continent, to the detriment of the British Exchange. The erroneous idea to which I allude is, the belief that the standard gold of the present reign is inferior to those which have preceded it; the real fact is, however, precisely the reverse, as the following extract, from the Report of Messrs. GARBETTS to the Lords of the Treasury, in 1782, will sufficiently prove.

* It is very probable, that the alloy was as much too abundant, in many similar pieces of the same coinage, as it was deficient in those here mentioned; for, it is certain, that the gold coins of JAMES II. and of CHARLES II. were, in the aggregate, much inferior to the present standard, as the annexed extract from Messrs. GARBETTS' Report sufficiently evinces.

Extract from Messrs. GARBETTS' *Report.*

" We had reason to believe that our gold coin was not esti-" mated, at foreign Mints, of the same fineness which our " standard declares it at, viz. 22 parts fine gold, and 2 parts " alloy; and, upon intimating this circumstance to the King's " and Master's Assayers, we were informed that a plan had been " settled, prior to the recoinage, for ascertaining the actual " fineness of the coin; and that guineas of every separate reign " had been melted into ingots of 15 pounds each, without in-" termixing the different reigns; that, from the contrary ends " of each ingot, they had made assays, which so nearly accorded, " as not to leave a doubt but the coins were worse than stand-" ard. The King's Assayers record of them was as follows. " *Viz.*

				s.	*d.*
" CHARLES II.	26 Tr. grs. in a lb. worse than standard		=	9	$10\frac{1}{4}$ pr ct
" JAMES II.	30 ———————	Ditto - -	=	11	$4\frac{1}{2}$
" WILLIAM III.	13 ———————	Ditto - -	=	4	11
" ANNE - -	7 ———————	Ditto - -	=	2	$7\frac{1}{2}$
" GEORGE I.	6 ———————	Ditto - -	=	2	$3\frac{1}{4}$
" GEORGE II.	3 ———————	Ditto - -	=	1	$1\frac{1}{2}$
" GEORGE III.	standard - -	standard - -		standard.	

" The accuracy of these assays was farther confirmed, by " nearly the same average of worseness being found upon more " than 170000 guineas, taken promiscuously from those reigns.

" In this place it should be observed, that if a pound of gold " coin does not vary more than 40 Troy grains in fineness, and " in weight, or in both together, it is allowed by the Mint in-" denture to pass as standard.

" During Lord CADOGAN's mastership, the average of weight " hath been only 2 grains 156 decimals lack per lb. which was

"paid by the moneyers at the scale; and, in upwards of 40000 "assays from the specimens of coin taken at the pix, (of "twenty-eight millions sent into circulation,) only one hath "deviated in fineness 3 grains in the pound; and, from the "public trial of them by the Goldsmith's Company, there hath "not been recorded more than 4 grains error in weight, and no "deviation in fineness.

"The Master of the Mint, therefore, might have varied in "fineness 36 Troy grains in a pound, or 13*s.* $7\frac{3}{4}$*d. per cent.* "without being liable to censure, if it did not appear he had "done it by design. This is sufficient to show the impropriety "of allowing a latitude of 40 Troy grains in a pound, for error "in fineness, or in weight together, or in either; and which "has so operated as to make our guineas of less value than we "declare them, and to be estimated, as we are informed, at the "Dutch Mints, 10 grains worse, and at Paris 15 grains Troy "worse; nor do they make any difference, either in Holland or "in France, between our present King's guineas and those of "former reigns.

"How far this deficiency affects the par of exchange in "money, and the Course of Exchange in bills, we submit to "consideration, as a matter of great importance."

Since the preceding pages were written, in which I have stated the numerous causes which tend to produce variations in the specific gravity of gold made standard by silver and copper, I have been induced to examine several of the English gold coins, and particularly those of the present reign.

The results of this examination, contained in the annexed Table, fully confirm my former sentiments, especially in respect to the impropriety of estimating the value of the coin of a

country, by insulated experiments on the specific gravity of a few pieces; for, a certain variation in the specific gravity of coin, independent of any alteration in its real value, is almost, if not absolutely, unavoidable.

Specific Gravity of some of the English gold Coins, at Temperature 60° of FAHRENHEIT.

TABLE IV.

Reign.			Date.	Specific gravity.
CHARLES	II.	a five-guinea piece - -	1681	17,825.
JAMES	II.	a two-guinea piece - -	1687	17,634.
WILLIAM	III.	a five-guinea piece -	1701	17,710.
GEORGE	I.	a quarter-guinea - -	1718	16,894.
GEORGE	II.	a guinea - - -	1735	17,637.
————		a two-guinea piece -	1740	17,848.
GEORGE	III.	one guinea - - -	1761	17,737.
————		one guinea - - -	1766	17,655.
————		one guinea - -	1774	17,726.
————		one guinea - - -	1775	17,698.
————		one guinea - - -	1776	17,486.
————		one guinea - -	1777	17,750.
————		one guinea - - -	1782	17,202.
————		one guinea - - -	1786	17,465.
————		one guinea - - -	1788	17,418.
————		five guineas - - -	1793	17,712.
————		ten half-guineas - -	1801	17,750.
————		15 seven-shilling pieces* -	1802	17,793.

* Supposing guineas, half-guineas, and seven-shilling pieces, to be made from the same metal, there is reason to expect (in a given comparative sum of each) an increase of specific gravity in the smaller coins, as a natural consequence of rolling, punching, annealing, blanching, milling, and stamping, the effects of which must become more evident, in proportion to the number of the small pieces required to form a given sum of the larger coins.

The average specific gravity of our gold coin, at the present time, may probably be estimated at 17,724.

SECTION III.

ON THE COMPARATIVE WEAR OF GOLD, WHEN ALLOYED BY VARIOUS METALS.

The comparative wear of gold, especially when in the form of coin, has never yet been ascertained; the opinions concerning it are therefore various. The most prevalent idea appears to be, that pure or ductile gold suffers more in a given time, under equal circumstances, than that which is of a harder quality.

Supposing this fact to be well established, it would not be difficult to render gold as hard as could be desired; for, as certain metals, when employed in equal proportions, cause gold to become of very different degrees of hardness, it would be easy even to make gold perfectly hard and brittle, without changing the standard proportion of alloy, provided that such extreme hardness was compatible with the process of coining.

But the question, whether ductile or hard and brittle gold sustains the greatest loss by wear, under equal circumstances, has by no means been fully determined; and Mr. HARRIS appears to have considered hard metal as the most liable to suffer, it being, when compared to that which is pure and soft, more brittle and less tenacious.*

Gold, when in the form of coin, appears to be generally exposed to three varieties of friction, *viz.*

1st. Friction between pieces of gold coin of a similar or of a different quality.

* An Essay upon Money and Coins, 1758, Part II. page 117.

2dly. Friction of gold coin against coin of other metals, such as silver and copper.

3dly. The friction which gold coins of various qualities suffer, when exposed to the action of certain substances, such as the particles or filings of metals, gritty powders, &c.

The consideration of these different modes of wear, points out the best method to be pursued in an experimental investigation.

The whole of the experiments which compose this section may therefore be divided into three subordinate series; the two first of which have been directed to the consideration of that part of the diminution of the coin which arises from the rubbing of one piece of metal against another; while,

The third of these subordinate series was intended to show the comparative power of gold, differently alloyed, to resist abrasion from sand or other gritty powders.

In the first set of experiments, 28 pieces of coin were fixed to a frame, and over each of them was placed another piece of coin, which was pressed against it by a weight. These upper pieces were all attached to a second frame, so that, by means of the motion communicated thereto by cranks, each upper piece was made to move about $\frac{3}{8}$ of an inch backwards and forwards on the lower one. This mode of experiment afforded an opportunity of trying the comparative diminution of gold differently alloyed, both when rubbed against pieces of the same and of a different alloy; and also of examining the difference of wear between pieces with plain and with stamped faces.

In the second series, 200 pieces of gold, differently alloyed, were inclosed in a wooden box, of a cubic figure, which was kept constantly turning round, till, by the repeated rubbing and striking of the pieces against each other, and against the sides of

the box, they were found to be sensibly diminished. This, like the experiments of the first set, was intended to show the comparative diminution of gold differently alloyed; but, whereas that shewed the effect of rubbing only, this shewed the joint effect of rubbing and striking, and was intended to imitate (although in a more violent degree) the effect produced upon coin by pouring it out of one bag or drawer into another.

The experiments of the third set were made by pressing the pieces to be examined against the rim of a flat horizontal wheel, by means of equal weights, so that, by turning the wheel round, they all suffered an equal degree of friction. That part of the wheel against which the pieces rubbed, was sprinkled or coated with some kind of powder, which was occasionally varied.

The above statement will convey a general idea of the manner of making the experiments; but, that the whole may be more fully comprehended, the following description of the instruments has been added by Mr. CAVENDISH.*

DESCRIPTION OF THE INSTRUMENTS.

It has been already observed that, in the first series of experiments, 28 pieces of coin were fixed to a frame, and that over each of them was placed another piece, which was pressed against it by a weight; and that these upper pieces were all connected to a second frame, so that, in consequence of the motion communicated thereto by cranks, each upper piece was rubbed backwards and forwards upon that which was under it.

Fig. 1, (Plate II.) represents a plan of this instrument; and Fig. 2 is a vertical section of it, drawn parallel to the line AB.

* The instruments were made by Mr. CUTHBERTSON, of Poland-street, who also had the care of them during the experiments which were made at his house.

The upper frame, or that to which the upper pieces of coin are connected, is of brass, and consists of four bars, Fig. 1, AB, B*b*, *ba*, and *a*A, with three cross bars C*c*, C*c*, C*c*.

The lower frame consists of a board, placed immediately under the upper frame, and is expressed in Fig. 2, by the letters LL.

The upper frame is supported by two vertical boards, extending the whole length of the sides B*b* and A*a*, so that the ends of them are seen in Fig. 2, and are denoted by the letters DD, DD. These boards are fastened to the upper frame, and to the table upon which the apparatus stands, by hinges, so that the upper frame can move freely in the direction BA, but can have no motion in the direction perpendicular thereto. These vertical boards are omitted in Fig. 1; for, as the intention of this description is not to give a detail of all the parts of the instruments, but only to explain their manner of acting, I have taken the liberty to omit such parts as tended to produce an intricacy in the figures, without being necessary to this object.

The disposition of the pieces of coin on the frames, is represented in Fig. 1. N*nn* denote one of the connecting pieces, by which the upper pieces of coin are connected to the upper frame, and in which the small circle represents the position of the coin; the large circle is the part which supports the weight, and *nn* the part by which it is connected to the upper frame.

To avoid confusion, neither these connecting pieces nor the pieces of coin are represented in Fig. 2; but, instead thereof, a section of one of these pieces is given in Fig. 3, upon a larger scale.

In this figure, LL is the lower frame, and C one of the bars of the upper frame; *y* is one of the lower pieces of coin, which

is bedded and fixed firmly in a brass socket *x*, fastened to the lower frame; *u* is the piece of coin to be rubbed against it, which, in like manner, is fixed in another brass socket *w*; N*n* is the connecting piece, by which this socket is connected to the bar C of the upper frame. This piece turns on pivots, in two studs *n*, fixed to the bar C, so that it can turn freely on those pivots in a vertical direction, but cannot be perceptibly shaken horizontally.

Z is the weight by which this connecting piece is pressed down; it is round, and is placed with its centre exactly over that of the socket *w*.

It must be observed that, in the construction of this machine, three things principally demanded attention.

1st. That the pieces of coin should all move equally.

2dly. That they should all be pressed against the lower pieces by the same weight. And,

3dly. That they should bear flat against them.

As to the first requisite, it is evident that the pieces must all move alike, excepting so far as proceeded from the springing of the parts of the machine, or from the shake in its joints, both of which were very small.

Secondly, as the connecting pieces move freely in a vertical direction, it is clear that the force with which the upper piece of coin is pressed against the lower one, depends only on its own weight, on that of the socket *w*, on that of the connecting piece N*n*, and on the weight Z by which it is loaded; so that the second requisite is thus easily obtained.

Thirdly, the connecting piece N*n* bears against the socket *w* only by the pin *p*, which enters into a hole in the centre of the socket, so that the two pieces must necessarily bear flat against

each other; but, as this pin alone would not have prevented the socket from turning round on its centre, two other pins $\Pi \Pi$ were fixed into the connecting piece, and entered into slits made in the socket near its circumference, allowing no more shake than was necessary to prevent it from sticking; and thus the motion round the centre was effectually prevented.

It may be observed, that the pieces might have been made to bear flat against each other by fixing the sockets *w* in gimbals; but, as the method above described was effectual, and much easier made, it was preferred.

It may be also remarked, that the breadth of the bars C*c*, as represented in Fig. 1, is not sufficient to prevent them from springing considerably; for this reason, a method of strengthening them was employed, which answered the purpose perfectly well, but is omitted in the drawing, as it could not be easily represented.

It was at first intended, that the lower frame should have remained fixed, and that only the upper one should have moved; but, in a previous trial, in which two pieces of metal were rubbed backwards and forwards upon each other in the same line, with a view to discover what weight would be necessary to make the pieces wear tolerably fast, I found that for a time they diminished slowly, but that little furrows or gullies were soon worn in them, and that then the diminution was rapid. I also observed, that the gullies in the upper pieces corresponded to those in the lower ones; so that it was impossible that the pieces of metal should touch each other in those places where the diminution was most rapid, and consequently the gullies must have been formed by the particles of metal which had been abraded, and which subsequently had become accumulated.

It seemed to me, that the most probable way to prevent the little furrows or gullies from being thus formed, would be, to construct the instrument in such a manner, that the direction in which the pieces rubbed upon each other should continually vary. The following contrivance was therefore adopted, by which the pieces were prevented from rubbing together twice in the same direction.

In this method, the lower frame, as well as the upper, is supported on two moveable vertical boards; but, whereas the boards supporting the upper frame are placed parallel to B*b*, in consequence of which the frame can move only in the direction BA, these are placed parallel to BA, so that the frame can move only in the direction B*b*.

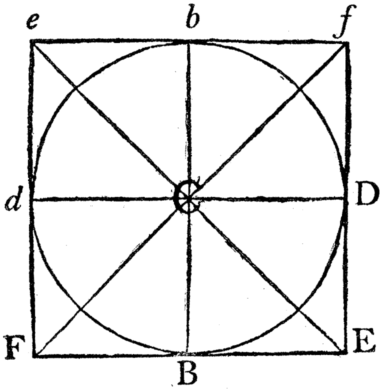
EE is the axis by which the upper frame is moved: this turns in fixed sockets at SS, and is turned at each end into the form of an eccentric circle, which acts as a crank; so that, by means of the levers EK, which at one end turn on these eccentric circles, and at the other end turn on joints fixed to the upper frame, this frame is made to move $\frac{1}{4}$ of an inch, in the direction BA, during one half of the revolution of the axis, and as much in the contrary direction, during the other half revolution.

ee is an axis of the same kind, serving to move the lower frame. HH is a windlass, which turns these two axes by means of the toothed wheels F, *f*, which work in the toothed wheels G, *g*, fastened to the axes EE and *ee*. TTTTT is the table upon which the apparatus stands.

The wheel F has 90 teeth, *f* has 75, and G, *g*, have each 20; so that the axis EE makes six revolutions while *ee* makes five; and, at a medium, these axes make about four revolutions to one

of the windlass. A counter is placed so as to show the number of revolutions of the windlass.

If the two frames had performed their vibrations in the same time, no advantage would have been gained, for the pieces of coin would still have moved upon each other always in the same line; but, as their vibrations are performed in different times, the effect is quite different; for, let C, in the annexed figure, be the centre of one of the pieces in the lower frame. Draw the lines B*b* and D*d* in the directions of the motion of the lower and upper frame, and equal to the space which those frames describe in one semi-revolution of the cranks, and complete the square of *ef* EF. Then, if the upper frame is moving with its greatest velocity in the direction D*d*, at the same time that the lower one is moving with its greatest velocity in the direction B*b*, the motion of the upper piece on the lower one will be in the diagonal *f*F; but if, at that time, the lower frame is moving with its greatest velocity in the contrary direction *b*B, the motion will be in the other diagonal E*e*.



If one frame is moving with its greatest velocity, while the other is at the extremity of its vibration, the motion will be in the circumference of the circle *b* D B *d*, inscribed within the square; and, in the intermediate cases, it will be in the circumference of an ellipsis, which is inscribed in the same square, and whose axes are in the diagonals *e*E and *f*F, but in which the proportion of the axes is continually changing; that axis which is placed in F*f* being sometimes the greatest, and at other times the least.

This contrivance, therefore, effectually prevented the pieces from moving upon each other always in the same line; and it seems also to have much diminished the disposition which they had to wear in gullies, but not intirely; for, from the following experiments it appears, that still some few particles would become occasionally collected, and then acted as a grinding powder, which accelerated the wear of the pieces. This was observed particularly to happen to the pieces of gold alloyed with an equal proportion of copper, and to the pieces of copper, which were also more frequently worn in furrows or gullies, than the other pieces of more ductile metal.

The motion of the pieces of coin upon each other, is greater than it would have been if only one frame had been made to move, nearly in the proportion of 3 to 2; so that the whole motion of the pieces, in each semi-revolution of the axes EE or *ee*, is about $\frac{3}{8}$ of an inch, and therefore it is about three inches in each revolution of the windlass.

The instrument employed in the second series of experiments, is so simple as not to require any drawing. It consisted only of a cubical box of oak, which measured 8 inches each way, within side. This box was moved by the axis EE of the former instrument, which was passed through the middle of two opposite sides, and was fixed in that position.

Fig. 4, represents a plan of the instrument used in the third series of experiments. *aaa* is a horizontal table, turning upon a vertical axis; and BBB*bbb* is a fixed frame surrounding it.

The pieces of coin are fastened to this fixed frame, by the same connecting pieces which were formerly employed, and are pressed down also by similar weights. The diameter of that part of the wheel against which the centres of the pieces of coin

are pressed, is 29 inches; so that, while this wheel makes one revolution, the pieces are rubbed against it through the whole circumference of this circle, that is, through $91\frac{1}{10}$ inches.

A shallow groove *ggg* is cut in this wheel, in that part against which the pieces are pressed, in order to confine the powders employed in the experiments; and the number of revolutions of the wheel are marked by a counter.

By the help of the instruments above described, it was proposed to determine, as accurately as possible,

1st. The comparative wear of soft and of hard gold.

2dly. Whether coins with flat or with raised surfaces suffer the greatest loss by friction, when subjected to it under similar circumstances.*

It is scarcely necessary to observe, that rigorously exact results could not be expected in all the minutiæ of experiments like the present; for, many circumstances, apparently but trivial, produced almost unsurmountable obstacles; but, nevertheless, these did not impede the essential objects from being investigated, and determined, in a manner sufficiently satisfactory.

Before the experiments are described, it will be proper to add, that, to obviate the irregular effects which would be produced by the inequality of the impressions usually employed for coins, Mr. CAVENDISH suggested a die, which was executed by Mr. PINGO, and which consisted of round prominencies regularly disposed over the surface, so that the effects which this

* Although coins with protuberances on their surfaces, have been generally supposed to suffer more by friction than those which are flat, yet, as this opinion has been questioned, and as several objections have been made to it by intelligent persons, it was thought expedient that the decision of the question should form part of the present investigation

impression produced, during friction, were uniformly the same in every direction.

The first experiments were intended to ascertain the different wear of gold made standard by various metals; and the pieces were rubbed against each other by means of the first-described apparatus, which I shall call No. 1.

Some preparatory experiments were also made, to try the effects of this machine, as well as to determine, in some measure, the comparative wear of gold made standard by copper, of a mixture of gold and copper in equal proportions, and, lastly, of copper.

Experiment 1.

Twelve pieces of the standard gold were first examined, and were placed so that six were opposed to six.

The brass frame, in which each upper piece was fixed, weighed 1604 grains; and it was found necessary to add to each a weight of lead, equal to 19825 grains; so that the pieces were rubbed against each other under the pressure of $19825 + 1604 = 21429$ grains $=$ 3 lb. 8 oz. 12 dts. 21 grs.*

The machine was then put in motion, until the index showed that 286690 revolutions had been performed; and, as a double crank acted during each revolution, the pieces were rubbed against each other alternately, in opposite directions, 573380 times, being twice the number of the revolutions.

The twelve pieces of standard gold, being taken out, were weighed, and were found to have lost 8,60 grs.

* This weight may appear to be very considerable; but it was not employed until repeated trials had proved the extreme difficulty, and almost impossibility, of producing any perceptible effect within a moderate period of time; and, even with this weight, the experiments were found to be exceedingly tedious. The only evil which resulted from such a pressure was, that the comparative wear of the fine gold appeared much more considerable than would have been the case, if a small weight could have been employed; some observations will therefore be found in the subsequent pages, which point out the necessity of making an allowance for this circumstance.

Experiment II.

This experiment was made upon twelve pieces of gold combined with an equal proportion of copper. The faces which were opposed were flat, and without any impression. After 70640 revolutions, these pieces had lost 103,11 grs.

Experiment III.

Twelve pieces of fine copper, perfectly flat, and not stamped, were next placed in the machine, and were taken out after 22200 revolutions; they had then lost 174,80 grs.

From these preliminary experiments it appears,

1st. That pieces of gold made standard by $\frac{1}{12}$ of copper, when rubbed against each other, suffer less than gold much debased by copper, or in which the latter metal is in equal proportion to the gold. And,

2dly. That pieces of gold alloyed with an equal quantity of copper, when rubbed against each other, suffer less than pieces of copper which are subjected to a similar process.

These essential objects being thus ascertained, the following experiment was made.

Experiment I.

Forty-eight pieces of gold, variously alloyed, which were perfectly flat and smooth, were fixed in the machine No. 1.

In this experiment, six pieces of each kind of gold were employed, and were so arranged, that three of each were made to rub against three of a similar quality; and the loss produced by friction, was afterwards estimated upon the whole of the six pieces.

The annexed Table will show the comparative loss sustained by the different kinds of gold.

TABLE I.

Total number of revolutions, 200300.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
1. Gold made standard by copper - -	844,90	844,90	—
2. Gold reduced to 18 carats by copper - -	747,60	747,60	—
3. Gold made standard by copper and silver -	829,20	829,10	,10
4. Gold made standard by silver - - -	937,20	937,10	,10
5. Gold 23 car. $3\frac{3}{4}$ grs. fine	854,0	849,80	4,20
6. Gold made standard by tin and copper - -	846,90	831,60	15,30
7. Gold made standard by iron and copper - -	825,10	803,50	21,60
8. Gold alloyed with an equal proportion of copper -	615,68	549,90	65,78

According to this statement, it appears, that fine gold of 23 car. $3\frac{3}{4}$ grs. suffered more by friction, under the above described circumstances, than gold made standard either by copper, by silver and copper, or by silver; but that this fine gold of 23 car. $3\frac{3}{4}$ grs. suffered less by wear than gold made standard by tin and copper, or by iron and copper; and, lastly, that copper, although it appears to be beneficial when in the proportion of $\frac{1}{12}$, and sometimes when it even amounts to $\frac{3}{12}$, yet, if employed in a larger proportion, for example, when equal to the quantity of gold, it then becomes highly detrimental,

for it not only much injures the colour of the precious metal, but also renders it extremely susceptible of the effects of friction. The presence of tin, or iron, appears also to render standard gold more liable to wear, than when the alloy consists only of copper, or of silver. So rapid was the loss of the pieces composed of equal parts of gold and copper, and of the others in which iron was present, that it was found necessary to remove the former, as well as those pieces which contained iron, after 105480 revolutions had been performed. The pieces containing tin were worn so thin, after 189000 revolutions, that they also were obliged to be taken out. As, therefore, the whole of the others sustained 200300 revolutions, it may be concluded, that the comparative loss of the pieces which were taken out, although very considerable, would have been much greater, had it been possible to have kept them in the apparatus during the whole period of the experiment.

The preceding experiment was made upon smooth, flat, unstamped pieces; it was therefore thought necessary to repeat it, in some measure, upon those which had been stamped by the die already described. In the following experiment, there was also a small variation, in respect to the quality of the series which were examined; for, the pieces composed of gold and copper in equal proportions were omitted, and some pieces of standard silver, and some of fine copper, were added.

Experiment II.

In this experiment, as in the former, pieces of similar quality were opposed to each other; and, in general, every circumstance was the same, excepting that the pieces were stamped, that the number of revolutions amounted only to 20680, and that all

the pieces remained in the apparatus till the experiment was finished.

TABLE II.

Number of revolutions, 20680.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
1. Gold made standard by copper - - -	846,90	846,30	0,60
2. Gold made standard by copper and silver -	834,80	833,60	1,20
3. Gold made standard by silver - -	940,30	936,80	3,50
4. Standard silver - -	518,70	515	3,70
5. Gold 23 car. $3\frac{3}{4}$ grs. fine -	846,40	841,80	4,60
6. Gold reduced to 18 carats by copper - -	745,80	741	4,80
7. Gold made standard by iron and copper -	825,60	818	7,60
8. Gold made standard by tin and copper - -	849,40	835,60	13,80
9. Copper - - -	496,90	450,60	46,30

Upon comparing the result of this experiment with that of the former, it may in like manner be observed, that gold made standard by copper, or by silver and copper, or by silver, suffered the least by wear; after which, standard silver, and then gold of 23 car. $3\frac{3}{4}$ grs. together with the others enumerated in the Table, were progressively more affected; and as, in the first experiment, the greatest loss was sustained by gold alloyed with

an equal proportion of copper, so, in this last experiment, the copper pieces suffered the most considerable diminution.

It must however be also remarked, that, contrary to the former experiment, gold reduced by copper to 18 carats, lost more than gold of 23 car. $3\frac{3}{4}$ grs.; and gold alloyed with tin and copper, lost more than that which was alloyed with copper and iron; but, in general, the coincidence of the results of the two experiments, appears to be as satisfactory as could with reason be expected.

Lastly, it appears, upon comparing the effects produced, with the number of revolutions employed in the two experiments, that we have a proof of the increase of wear which attends the friction of raised or embossed surfaces.

Hitherto, the effects produced by the friction of pieces of a similar quality only had been examined; but, in order to ascertain the comparative wear which would be occasioned by rubbing pieces of a similar and of a different quality against each other, by one operation, the following experiment was made.

Experiment III.

This experiment was made upon 54 unstamped pieces of gold, the different qualities of which are expressed in the annexed Table; and it is necessary here to observe, that standard gold is always to be understood from the terms gold alloyed with silver, gold with silver and copper, &c. excepting when other proportions are expressly stated.

TABLE III.

Number of revolutions, 229040.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
1. Gold 23 car. $3\frac{3}{4}$ grs. -	142,50	139,50	3,0
2. Gold 23 car. $3\frac{3}{4}$ grs. -	140,50	137,20	3,30
3. Gold alloyed with silver -	153,60	153,60	—
4. Gold alloyed with silver -	158,90	158,80	0,10
5. Gold with silver and copper	137,40	131	6,40
6. Gold with silver and copper	136,80	133,50	3,30*
7. Gold with copper - -	135,30	135,30	—
8. Gold with copper -	135,40	135,30	0,10
9. Gold with iron and copper	134	116,80	17,20
10. Gold with iron and copper	133,80	119,80	14,0
11. Standard silver -	84,50	84,40	0,10
12. Standard silver - -	84,50	84,40	0,10
13. Copper - - -	84,70	34,60	50,10
14. Copper - -	82,30	43,60	38,70
15. Standard silver -	82,90	68	14,90
16. Copper - - -	82,40	46,60	35,80
17. Gold made standard by copper - - -	117,10	83,40	33,70
18. Copper - -	66,80	23,50	43,30
19. Gold with copper -	134,40	129,20	5,20
20. Standard silver -	83,30	75,10	8,20
21. Gold with copper -	138,70	138,60	0,10
22. Gold with silver -	152,90	152,80	0,10
23. Gold with copper -	136,20	132,90	3,30
24. Gold with iron and copper	137,10	130	7,10

* These two pieces slipped out of the sockets of the machine, and were so much injured, that it would be improper to consider the loss mentioned in the Table as that which they would have suffered by regular friction.

TABLE III. (*continued.*)

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
25. Gold with copper -	142	141,90	0,10
26. Gold with silver and copper	137,80	137,80	—
27. Gold 23 car. 3¾ grs. -	137,80	137,70	0,10
28. Standard silver -	84,10	84	0,10
29. Gold 23 car. 3¾ grs. -	138,10	138,10	—
30. Gold with silver -	155,40	155,40	—
31. Gold 23 car. 3¾ grs. -	137,60	136,10	0,50
32. Gold with copper - -	144,20	144,60*	—
33. Gold 23 car. 3¾ grs. -	140,10	136,30	3,80
34. Gold and copper in equal parts - - -	103,40	101,80	1,60
35. Gold with silver - -	153,40	153,40	—
36. Gold reduced by copper to 18 carats - -	121,80	121,80	—
37. Gold with silver -	153,40	151	2,40
38. Gold and copper in equal parts - - -	101,80	101,60	0,20
39. Gold with silver -	152,10	152,10	—
40. Gold with silver and copper	137,50	137,50	—
41. Gold with silver and copper	139,90	139,90	—
42. Gold with iron and copper	135,90	135,80	0,10
43. Gold with copper - -	136,90	125,70	11,20
44. Gold and copper in equal parts - - -	103,10	99,90	3,20
45. Gold with copper -	140	140	—
46. Gold with tin and copper	138	138	—
47. Gold with copper, cast in sand - - -	132,80	126,30	6,50
48. Gold with iron and copper	133,80	129,20	4,60
49. Gold with copper, cast in sand - - -	136	136	—
50. Gold of 18 carats -	125,30	125,30	—

* In this instance, there was an increase of weight, amounting to 0,40.

TABLE III. (*continued.*)

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
51. Gold with iron and copper	136,50	129,30	7,20
52. Gold with tin and copper	136,70	129	7,70
53. Gold with tin and copper	139,20	133,40	5,80
54. Gold of 18 carats - -	125,30	125,50*	—

The different pieces mentioned in the foregoing Table, are enumerated according to the order of their arrangement in the apparatus; and it is proper to observe, that the pieces of copper, Nos. 13 and 14, as well as the piece of gold made standard by copper, No. 17, and the piece of copper No. 18, were worn so thin during the experiment, that they were taken out after 114520 revolutions; but all the other pieces sustained twice that number, or 229040 revolutions.

When the preceding experiment was terminated, it was observed, that,

No. 15, or standard silver, was coated slightly by the copper No. 16.

That, No. 19, or gold made standard by copper, was coated by the standard silver No. 20.

That, No. 28, or standard silver, was slightly coated by the gold of 23 car. $3\frac{3}{4}$ grs. or No. 27.

That, part of No. 31, or gold of 23 car. $3\frac{3}{4}$ grs. adhered to the gold made standard by copper, or No. 32; and, that the gold alloyed by an equal proportion of copper, No. 38, was slightly coated by the gold made standard by silver, No. 37. But, to avoid repetition, it appears proper that other observations should be deferred, until the following experiment has been described.

* Increased in weight 0,20.

Experiment IV.

This resembled the former experiment, excepting that stamped pieces were employed.

Table IV.

Number of revolutions, 83520.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
1. Gold 23 car. $3\frac{3}{4}$ grs. -	142,10	142,50*	—
2. Gold 23 car. $3\frac{3}{4}$ grs. -	142,20	140,50	1,70
3. Gold with silver -	154,40	153,60	0,80
4. Gold with silver - -	159	158,90	0.10
5. Gold with silver and copper	137,60	137,40	0,20
6. Gold with silver and copper	137,70	136,80	0,90
7. Gold with copper -	135,50	135,30	0,20
8. Gold with copper - -	135,50	135,40	0,10
9. Gold with iron and copper	137,20	134	3,20
10. Gold with iron and copper	135,80	133,80	2,0
11. Standard silver -	85,80	84,50	1,30
12. Standard silver - -	86,20	84,50	1,70
13. Copper - - -	82,40	38	44,40
14. Copper - - -	82,10	46	36,10
15. Standard silver - -	85,40	82,90	2,50†
16. Copper - - -	85	82,40	2,60
17. Gold with copper -	140,30	117,10	23,20
18. Copper - - -	82,30	66,80	15,50
19. Gold with copper - -	134,50	134,40	0,10‡
20. Standard silver - -	85,20	83,20	1,90

* Increased in weight 0,40.

† The piece of silver was slightly coated by the copper.

‡ The standard gold was coated by the silver.

TABLE IV. (*continued.*)

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
21. Gold with copper -	139	138,70	0,30
22. Gold with silver - -	153,50	152,90	0,60
23. Gold with copper -	138,70	136,20	2,50*
24. Gold with iron and copper	138,50	137,10	1,40
25. Gold with copper -	142	142	—
26. Gold with silver and copper	137,80	137,80	—
27. Gold 23 car. $3\frac{3}{4}$ grs. -	140,10	137,80	2,30†
28. Standard silver - -	86,44	84,10	2,34
29. Gold 23 car. $3\frac{3}{4}$ grs. -	139,80	138,10	1,70
30. Gold with silver - -	156,80	155,40	1,40
31. Gold 23 car. $3\frac{3}{4}$ grs. -	140,80	137,60	3,20
32. Gold with copper -	141 60	144,20‡	—
33. Gold 23 car. $3\frac{3}{4}$ grs. -	141	140,10	0,90
34. Gold and copper in equal parts - - -	103,38	103,40§	—
35. Gold with silver - -	154,50	153,40	1,10
36. Gold of 18 carats -	121,02	121,80‖	—
37. Gold with silver -	155,50	153,40	2,10
38. Gold and copper in equal parts - - -	102	101,80	0,20¶
39. Gold with silver -	153,60	152,10	1,50
40. Gold with silver and copper	140	137,50	1,60

* The gold alloyed with copper was coated by the gold alloyed with iron and copper.

† The fine gold was coated by the silver.

‡ The standard gold was coated by the fine gold, and had gained 2,60.

§ The gold alloyed with an equal proportion of copper was coated by the fine gold, and had gained ,02.

‖ The gold of 18 carats was coated by the gold alloyed with silver, and had gained 0,78.

¶ The gold alloyed with an equal part of copper was coated by the gold alloyed with silver.

TABLE IV. (*continued.*)

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
41. Gold with silver and copper	141	139,90	1,10 *
42. Gold with iron and copper	137,50	135,90	1 60
43. Gold with copper -	138,40	136,90	1,50
44. Gold and copper in equal parts - - -	103,14	103,10	,04 †
45. Gold with copper -	141	140	1,0 ‡
46. Gold with tin and copper	144,50	138	6 50
47. Gold with copper, cast in sand - - -	135,40	132,80	2,60
48. Gold with iron and copper	135,80	133,80	2,0
49. Gold with copper, cast in sand - - -	136,03	136	0,03
50. Gold of 18 carats -	125,38	125,30	0,08
51. Gold with iron and copper	137,40	136,50	0,90
52. Gold with tin and copper	141,80	136,70	5,10
53. Gold with tin and copper	140,90	139,20	1,70
54. Gold of 18 carats - -	125,02	125,30 §	—

* The gold alloyed with silver and copper was coated by the gold alloyed with iron and copper.

† The gold alloyed with an equal part of copper was coated by the gold made standard with copper.

‡ The gold alloyed with copper was coated by the gold alloyed with tin and copper.

§ Increased in weight 0,28.

The above effects sufficiently show, that the more ductile metals are always worn by those which are comparatively harder; and, in every experiment, it was constantly observed that the latter became coated by the metal of the former. This coating was commonly spread thinly over the surface; but, in some few instances, (especially when a very hard metal rubbed against one which was very soft,) the particles of the latter, instead of being spread over the whole surface, became accumulated, so as to form little protuberances or knobs.

It has been already observed, that the foregoing experiment was similar to that which preceded it, in respect to the quality, number, and arrangement of the pieces; and the only difference was, that the pieces employed in the present experiment were stamped with the die formerly mentioned.

As the continuance of the friction was not so long as that of the former experiment, it was not found necessary to remove any of the pieces, so that the complete series remained in the apparatus, during the whole of the experiment.

It will now be proper to compare the results of these two last experiments; and, in order to do this with more perspicuity, the following comparative Table, and some observations upon it, have been added.

COMPARATIVE TABLE, V.

Number of revolutions, 229040.				Number of revolutions, 83520.			
Plain or unstamped pieces.				Stamped pieces.			
Quality.		Loss.		Quality.		Loss.	
		Grains.				Grains.	
Gold 23 car. $3\frac{3}{4}$ grs.	1	3,0	6,30	Gold 23 car. $3\frac{3}{4}$ grs.	1	—	1,70 gained ,40 1,30
	2	3,30			2	1,70	
Gold made stand. by silver	3	—	0,10	Gold made stand. by silver	3	0,80	0,90
	4	0,10			4	0,10	
Gold with silver & copper	5	6,40	9,70*	Gold with silver & copper	5	0,20	1,10
	6	3,30			6	0,90	
Gold with copper -	7	—	0,10	Gold with copper -	7	0,20	0,30
	8	0,10			8	0,10	
Gold with iron and copper	9	17,20	31,20	Gold with iron and copper	9	3,20	5,20
	10	14,0			10	2,0	
Standard silver - -	11	0,10	0,20	Standard silver - -	11	1,30	3,0
	12	0,10			12	1,70	
Copper - -	13	50,10	88,80	Copper - -	13	44,40	80,50
	14	38,70			14	36,10	

* The considerable diminution of these pieces was caused by an accident, which has been mentioned in a former note.

Comparative Table V. (*continued.*)

Plain or unstamped pieces.			Stamped pieces.		
Quality.		Loss.	Quality.		Loss.
		Grains.			Grains.
Standard silver - -	15	14,90	Standard silver - -	15	2,50
Copper - - -	16	35,80	Copper - - -	16	2,60
Gold with copper - -	17	33,70	Gold with copper -	17	23,20
Copper - - -	18	43,30	Copper - - -	18	15,50
Gold with copper - -	19	5,20	Gold with copper - -	19	0,10
Standard silver - -	20	8,20	Standard silver - -	20	1,90
Gold with copper - -	21	0,10	Gold with copper - -	21	0,30
Gold with silver - -	22	0,10	Gold with silver - -	22	0,60
Gold with copper - -	23	3,30	Gold with copper - -	23	2,50
Gold with iron and copper -	24	7,10	Gold with iron and copper -	24	1,40
Gold with copper - -	25	0,10	Gold with copper - -	25	—
Gold with silver and copper	26	—	Gold with silver and copper -	26	—
Gold 23 car. 3¾ grs. -	27	0,10	Gold 23 car. 3¾ grs. -	27	2,30
Standard silver - -	28	0,10	Standard silver - -	28	2,34
Gold 23 car. 3¾ grs. - -	29	—	Gold 23 car. 3¾ grs. - -	29	1,70
Gold with silver - -	30	—	Gold with silver - -	30	1,40
Gold 23 car. 3¾ grs. -	31	0,50 gained.	Gold 23 car. 3¾ grs. -	31	3,20 gained.
Gold with copper - -	32	0,40	Gold with copper - -	32	2,60
Gold 23 car. 3¾ grs. -	33	3,80	Gold 23 car. 3¾ grs. -	33	0,90 gained.
Gold and copper in equal parts	34	1,60	Gold and copper in equal parts	34	,02
Gold with silver - -	35	—	Gold with silver - -	35	1,10 gained.
Gold reduced by copper to 18 car.	36	—	Gold of 18 carats - -	36	0,78
Gold with silver - -	37	2,40	Gold with silver - -	37	2,10
Gold and copper in equal parts	38	0,20	Gold and copper in equal parts	38	0,20
Gold with silver - -	39	—	Gold with silver - -	39	1,50
Gold with silver and copper -	40	—	Gold with silver and copper	40	1.60
Gold with silver and copper -	41	—	Gold with silver and copper -	41	1,10
Gold with iron and copper -	42	0,10	Gold with iron and copper -	42	1,60
Gold with copper - -	43	11,20	Gold with copper - -	43	1,50
Gold and copper in equal parts	44	3,20	Gold and copper in equal parts	44	,04
Gold with copper - -	45	—	Gold with copper - -	45	1,0
Gold with tin and copper -	46	—	Gold with tin and copper -	46	6.50
Gold with copper, cast in sand	47	6,50	Gold with copper, cast in sand	47	2,60
Gold with iron and copper -	48	4.60	Gold with iron and copper -	48	2,0
Gold with copper, cast in sand	49	—	Gold with copper, cast in sand	49	,03
Gold of 18 carats - -	50	—	Gold of 18 carats - -	50	,08
Gold with iron and copper -	51	7,20	Gold with iron and copper -	51	0,90
Gold with tin and copper -	52	7,70	Gold with tin and copper -	52	5,10
Gold with tin and copper -	53	5,[illegible]0 gained.	Gold with tin and copper -	53	1,70 gained.
Gold of 18 carats - -	54	0,20	Gold of 18 carats - -	54	0,28

From this comparative Table it appears, that although the experiments were made with correct instruments, and with every possible precaution, yet perfect accuracy could not be attained, nor indeed expected; for, various minute and unavoidable circumstances contributed to produce very sensible effects; even a few particles, collected and retained between the pieces during the operation, frequently prevented the loss by friction from being correctly ascertained. Another cause of irregularity in the comparative wear of the pieces, arose from a small degree of unevenness in the level of many of the unstamped faces, which, although scarcely perceptible to the eye, became sufficiently apparent when friction commenced, and pointed out the necessity of relying only upon general results. It would not, therefore, be right to lay too great a stress upon very small and only occasional deviations in the results; and consequently the small difference of a few fractional parts do not merit attention; for the same reason, it would not be proper to form an opinion upon certain results, which, without any very apparent cause, seem to be in opposition to each other. The most candid and certain mode to be adopted, under these impediments, appears therefore to be, that of taking into consideration only such effects as were general, under every change of circumstance, and which were invariably more or less the same, however the mode of operation might be diversified. Upon this basis it may be concluded, that the preceding experiments prove,

1st. That fine gold, or of 23 car. $3\frac{3}{4}$ grs. when exposed to friction against gold of an equal quality, under the pressure of a considerable weight, suffers a very notable loss; and, although various circumstances seemed to indicate that but little effect, in

respect to abrasion, is produced under a less weight, yet it must be remembered, that the first case may occur.*

Moreover, by the late experiments it has been proved, that fine gold, under all circumstances, is more subject to have any embossed or raised parts of its surface obliterated than any variety of alloyed gold; not always, nor indeed so much, by actual abrasion, as by having the protuberant parts pressed and rubbed into the mass, in consequence of its extreme softness and ductility.†

2dly. That fine gold, or of 23 car. $3\frac{3}{4}$ grs. when rubbed against the various kinds of alloyed gold, always or generally suffers the greatest comparative loss.

3dly. That gold reduced to 22 carats, or to standard, by silver, or by silver and copper, or merely by copper, suffers by friction, under general and similar circumstances, a smaller diminution than the fine gold abovementioned; and, with or without abrasion, the protuberant parts on the surfaces of these pieces remain

* It is proper to remark, that the preceding experiments were made under a much greater weight than can be supposed to operate generally during the circulation of money; and as, by some previous experiments, a less weight was found to produce, during a certain time, little or no effect, it may be suspected, that although, under a great pressure, fine or very ductile gold sustains a greater loss than some of those which are reduced to standard, yet, under a less pressure, or such as that which most commonly prevails in the course of the usual wear of coin, the reverse may probably be the case; for then the same causes operate with less rapidity, during a long period of time. From many various circumstances, there is reason therefore to believe, that the wear of coin against coin of a similar quality is, under a small or very moderate weight, in the inverse ratio to the degree of ductility; but this is only to be understood in the abovementioned case, of coin rubbed against coin of equal quality.

† This is, however, of much consequence; for, although coin may not suffer by actual abrasion, yet, if the impression made upon it can so soon be destroyed, it follows of course, that the pieces become (although still allowed to be current) no better than mere blanks, or fragments of a bar or ingot.

much more permanent, under all circumstances, than those of the fine gold. The difference of wear between the three kinds of standard gold abovementioned, does not in reality appear to be very considerable; but, upon the whole, the preference may be given to gold alloyed with a mixture of silver and copper, or to that which has only copper for the alloy.

4thly. That gold made standard partly by the addition of iron or tin, sustains a greater loss by friction than either of the three kinds of standard gold abovementioned.

5thly. That gold reduced to 18 carats by copper, is more liable occasionally to wear, in a small degree, than the three kinds of standard gold which have been lately mentioned, provided that the friction takes place between pieces of equal quality; but, in the contrary case, the principal loss always falls on the soft or standard gold, when it is opposed to gold of 18 carats, which is considerably harder.

6thly. That gold more debased than that of 18 carats, such as gold alloyed with an equal proportion of copper, suffers very considerably more than any of the kinds hitherto mentioned, provided that the pieces are of the same quality; but, on the contrary, fine and standard gold experience a very great loss, when exposed to the action of this debased gold, while the loss of the latter is comparatively much less.

7thly. That the wear of standard silver appears to be nearly equal with that of fine gold; but more than that of gold made standard by silver or by copper, and less than that of gold much debased by copper.

8thly. That, as gold which is not inferior to standard wears in general less than standard silver, so does this last suffer much less than copper.

The loss sustained by copper, when rubbed against copper, is infinitely more than that of the former metals; and, when these are exposed to the action of copper, they, as well as the copper, suffer a very considerable loss. This appears from the general results of these experiments, which prove, that pieces of metal which are the most subject to wear, are those which produce the greatest loss upon other pieces of metal, when rubbed against them; and it is remarkable, that *in such a case*, the loss does not always fall on one in preference to the other; so that the wear can only be considered in the aggregate, although one of the pieces may be regarded as the principal cause.

In order, however, to illustrate the results of the preceding experiments, as far as they concern the softer and harder kinds of standard gold, and to ascertain more fully the comparative wear of flat and smooth surfaces with that of such as were partly protuberant, the following experiment was made.

Experiment V.

In this experiment, two kinds of standard gold were employed, *viz.*

1st. Gold made standard by fine Swedish copper, which was very ductile; and,

2dly. Gold made standard by a mixture of fine Swedish copper and dollar copper. This was as brittle as was compatible with rolling and stamping; and was prepared by melting gold made standard by fine Swedish copper, with an equal quantity of gold rendered brittle by the standard proportion of Swedish dollar copper, which was mentioned in the first section of this Paper.

It may here be observed, that a distinction must be made

between hard and brittle metal. If a metal is disposed to crack when rolled, without requiring any extraordinary force to enable it to pass the rollers, then it may be regarded as brittle; but, if it requires an extraordinary force to make it pass the rollers, and is not disposed to crack, then it may be considered as hard.

The latter quality, or hardness, appears however in some degree to be produced, when a very brittle metal is gradually rendered ductile; at least it is difficult to distinguish a certain degree of hardness from a certain degree of brittleness, when the extremes of ductility and brittleness are nearly in equilibrio; and this was found to be the case, when gold was required to be made only so brittle as still to be capable of being rolled and stamped.

Some of the Swedish copper dollars were found to make gold very brittle, when employed as the alloy in standard proportion; but then this extreme brittle quality was incompatible with rolling and stamping. The standard gold, therefore, which was thus become so very brittle, was mixed with different proportions of very ductile standard gold, which had been alloyed with fine Swedish copper; and, after several trials, it appeared, that a mixture of equal parts of the very brittle standard gold and of that which was ductile, formed a metal the best adapted to the present purpose, as it then remained but just sufficiently ductile to be rolled and stamped.

TABLE VI.

Number of revolutions, 220000.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
1. Gold made standard by fine Swedish copper, 4 pieces, unstamped - -	487,90	487,90	—
2. Gold made standard by fine Swedish copper, 4 pieces, stamped - - -	486,30	484	2,30
3. Gold made standard by equal parts of fine Swedish and dollar copper, 4 pieces, unstamped - -	564,70	564,70	—
4. Gold made standard as above, 4 pieces, stamped	564,30	550,40	13,90
5. Gold with fine copper, 2 pieces, unstamped -	244	243,90	0,10
Gold with fine and dollar copper, 2 pieces, unstamped	285,50	285,50	—
6. Gold with fine copper, 2 pieces, stamped - -	239,50	233,60	5,90
Gold with fine and dollar copper, 2 pieces, stamped -	279,90	276,50	3,40

This experiment proves,

1st. That very ductile standard gold, when exposed to the friction of gold of a similar quality, suffers less by abrasion than gold which is comparatively brittle, or harder, and which is subjected to friction under the same circumstances.

2dly. That when soft gold and brittle or hard gold rub against

each other, the greatest loss is sustained by the soft gold. And,

3dly. That pieces which have raised or embossed surfaces, suffer a greater loss, under every circumstance, than those which are smooth and flat.

The whole of the foregoing experiments were made with the machine called No. 1; and, as the friction was continued, in each experiment, during many days, with a pressure upon each couple of pieces equal to 3 lbs. 8 oz. 12 dts. and 21 grs., and as (considering the severity of such a trial) the loss sustained by the pieces, separately or collectively, was not very considerable, it may with reason be inferred, that standard gold does not easily suffer abrasion by the friction of metal against metal, or of coin against coin, especially under the circumstances which commonly prevail during the circulation of money.

In the machine No. 1, the pieces of gold were opposed face to face; it now therefore appeared proper, that the facts thus ascertained concerning the wear of gold, of different degrees of ductility, should be farther examined, and corroborated by a different method. To effect this, the second of the machines before described, which I shall call No. 2, was employed.

It has been already observed, that this machine was a cubic box, of 8 inches withinside, formed of oak one inch in thickness, through which, a strong axis of iron passed, so as to be turned by a wheel and pinion.

Experiment with the Machine No. 2.

Two hundred pieces of gold, of five different qualities, were employed in this experiment; and it must be previously remarked,

that twenty pieces of each kind of gold were plain and smooth, but that the others were stamped with the die which has several times been mentioned. The two hundred pieces were mingled, and were inclosed within the cubic box.

The following were the qualities of the gold,

1. Gold of 23 car. $3\frac{3}{4}$ grs.
2. Gold made standard by silver.
3. Gold made standard by silver and copper.
4. Gold made standard by fine Swedish copper.
5. Gold made standard by equal parts of fine Swedish copper and dollar copper.

TABLE VII.

Number of revolutions, 71720.

Quality.	Weight before friction.	Weight after friction	Loss.
	Grains.	Grains.	Grains.
1. Gold 23 car. $3\frac{3}{4}$ grs. 20 pieces, unstamped -	2716,8	2624	92,8
Gold 23 car. $3\frac{3}{4}$ grs. 20 pieces, stamped - - -	2691,4	2595,8	95,6
2. Gold made standard by silver, 20 pieces, unstamped	2719	2655,5	63,5
Gold made standard by silver, 20 pieces, stamped -	2722,6	2662,5	60,1
3. Gold made standard by silver and copper, 20 pieces, unstamped - -	2720	2708	12
Gold made standard by silver and copper, 20 pieces, stamped - - -	2724,7	2713	11,7

TABLE VII. *(continued.)*

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
4. Gold made standard by fine Swedish copper, 20 pieces, unstamped - -	2746	2728	18
Gold made standard by fine Swedish copper, 20 pieces, stamped - -	2738,1	2718,9	19,2
5. Gold made standard by equal parts of fine and dollar copper, 20 pieces, unstamped - - -	2799,5	2786,5	13
Gold made standard by equal parts of fine and dollar copper, 20 pieces, stamped	2802,7	2790,6	12,1

	Grains.
Total weight of the unstamped pieces, before friction,	13701,3
Total weight of the stamped pieces, before friction -	13679,5
Total loss of the unstamped pieces - - -	199,3
Total loss of the stamped pieces - - - -	198,7

The 71720 revolutions of the preceding experiment, were performed in 40 hours; after which, the pieces were taken out, as those parts of the hollow cube which were the most exposed to friction, were nearly half worn through.

All the pieces appeared to have suffered more on the edges than on the faces; and those which were stamped had the impression more or less obliterated or flattened, in proportion to their respective degree of ductility, or to the loss which,

according to the result of this experiment, they had relatively sustained.

The different pieces, after the experiment, had a curious appearance; for, on the edges, which were become round and polished, a small regular raised bead or moulding was formed, which surrounded each face, like a frame; and both faces were become more or less concave.

The original diameter of the pieces was also diminished, nearly according to their different degrees of ductility, and according to the loss which they had experienced in consequence of the operation.

The measure of the diameters of the pieces, after the experiment, was,

Gold 23 car. $3\frac{3}{4}$ grs. eight-tenths of an inch and $\frac{3}{40}$.

Gold alloyed with silver, nine-tenths of an inch.

The others varied little from nine-tenths and $\frac{1}{40}$; which was less, by about $\frac{1}{40}$ of an inch, than the original diameter of the pieces; and it was evident, that the pieces of fine gold and those consisting of gold alloyed with silver, being the most ductile of the whole series, had suffered the greatest loss, and also that they were those which became the most diminished in diameter. Upon the whole, therefore, considering the general result of this experiment, it appears to corroborate what has been asserted concerning the former experiments, *viz.* that soft or ductile gold suffers the greatest loss, when exposed to friction in contact with gold which is comparatively harder. The effects upon gold of 23 car. $3\frac{3}{4}$ grs. and upon gold alloyed with silver, fully prove this; and, if a perceptible difference was not found between the others, in this experiment, it must be ascribed to the difference in ductility being too small to resist the general effect of the friction;

and, allowing that to be the case, such a difference cannot be deemed worthy of notice.

Before the observations upon the foregoing experiment are concluded, it may be proper to add, that no essential difference between plain and stamped pieces could be observed, when friction was applied in the way abovementioned.

Here terminated the experiments which were intended to ascertain the effects arising from the friction of coin against coin; but it will probably be better to postpone the general observations upon this part, until the experiments have been described which were made with the machine Fig. 3.

By this apparatus, which may be called No. 3, various pieces were exposed to the action of certain powders and filings of metals, which were separately sprinkled upon the horizontal table.

The pieces were properly fixed in their respective sockets and frames, and were placed so as to bear upon the table, with or without additional weights.

The table was moved by a wheel and pinion, so calculated as to avoid too rapid a motion; and the revolutions were denoted, as in the former experiments, by means of a counter.

Experiments made with the Machine No. 3.

In the first experiment which was made with this instrument, the table was covered with fine powdered whiting, and the pieces were arranged as follows*

* Two pieces of each of the different kinds of gold, &c. were subjected to this experiment.

Experiment 1.

TABLE VIII.

Number of revolutions, 11880.			
Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Gold 23 car. $3\frac{3}{4}$ grs. unstamped	284,20	283,40	0,80
Gold 23 car. $3\frac{3}{4}$ grs. stamped	283,90	280,10	3,80
Gold made standard by silver, unstamped - - -	293	292,30	0,70
Gold made standard by silver, stamped - - -	289,70	287	2,70
Gold made standard by silver and copper, unstamped -	280,80	280,50	0,30
Gold made standard by silver and copper, stamped -	282,20	280,40	1,80
Gold made standard by fine copper, unstamped -	245,70	245	0,70
Gold made standard by fine copper, stamped - -	242,50	240,60	1,90
Gold made standard by equal parts of fine and dollar copper, unstamped - -	245,30	245,10	0,20
Gold made standard by equal parts of fine and dollar copper, stamped - -	248,90	247,70	1,20
Gold of 18 carats,* unstamped	209,70	209,50	0,20
Gold of 18 carats, stamped -	207,30	206,50	0,80
Standard silver, unstamped -	144,20	143,20	1
Standard silver, stamped -	145,40	143,60	1,80
Fine copper, unstamped -	151	150,80	0,20
Fine copper, stamped - -	154,60	154,40	0,20

* The gold of 18 carats employed in these experiments, was alloyed with copper; but I am well convinced that gold reduced to 18 carats by an alloy composed of silver and copper in different proportions, will be more easily worked than when copper alone forms the alloy, and will, in many respects, be found very useful by goldsmiths and jewellers.

From the result of this experiment it appears, that by the action of a soft powder, such as whiting, fine gold sustained a greater loss than gold made standard by silver; and again, that this, being more ductile than any of the other kinds of standard gold, suffered more than those; for it is evident, that the wear produced by this experiment, was in proportion to the softness or ductility of the pieces of metal, those which were comparatively hard, being in general those which were the least abraded.

In the same order also, the difference between plain and stamped surfaces was perceptible.

It must be likewise remarked, that although copper, when rubbed against copper, experiences a much greater loss than either gold or silver, yet, when copper is exposed to the action of a powder like whiting, as in the present experiment, it is, on the contrary, the metal which is abraded in the smallest degree.

Lastly, it may be observed, that this experiment fully proves, that the wear is much greater upon raised or embossed surfaces than upon those which are flat and plain; and that, in proportion to the ductility of the metal, the difference of wear between plain and stamped pieces becomes more apparent.

The preceding experiment was made with a weight upon each piece, equal to 3 lbs. 8 oz. 12 dts. and 21 grs. which was the same as was employed in every experiment made with the machine No. 1. But, previous to the following experiment, in which fine white writing-sand was used instead of whiting, it was found, after 5280 revolutions, that no inference could be made when this weight was employed; for the sand soon began to accumulate upon the faces of the pieces, and adhered like a dark gray or blackish crust, which with great difficulty was detached. In consequence of this, the wear of the pieces

was extremely unequal; and, towards the conclusion of the experiment, they were so coated by the abovementioned crust, as no longer to be abraded; and the horizontal wooden table alone experienced the effects of the friction.

After various trials, it was found necessary to remove the leaden weights, = 19825 grains, which had been hitherto always employed. So that the pieces in the experiment now to be related, were only pressed upon the table by the weight of their respective brass frames, = 1604 grains; and, in addition to other precautions in this experiment, the sand was not loosely scattered, but was cemented upon the horizontal table by a solution of isinglass.

By these means, the following experiment was made with success.*

Experiment II.

TABLE IX.

Number of revolutions, 880.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Gold 23 car. $3\frac{3}{4}$ grs. unstamped	286,70	268,60	18,10
Gold 23 car. $3\frac{3}{4}$ grs. stamped	288,70	286,60	20,10
Gold made standard by silver, unstamped - - -	271,30	254,80	16,50
Gold made standard by silver, stamped - - -	271,40	253,80	17,60

* Two pieces of each of the various kinds of gold, &c. were subjected to this experiment.

TABLE IX. *(continued.)*

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Gold made standard by silver and copper, unstamped -	282,70	271,10	11,60
Gold made standard by silver and copper, stamped -	282,20	267,20	15
Gold made standard by fine copper, unstamped -	243,70	228,20	15,50
Gold made standard by fine copper, stamped - -	243,60	229,70	13,90
Gold made standard by equal parts of fine and dollar copper, unstamped - - -	249,70	237,80	11,90
Gold made standard by equal parts of fine and dollar copper, stamped - -	249,60	234,80	14,80
Gold of 18 carats, unstamped	208,30	199,30	9
Gold of 18 carats, stamped -	209	197,10	11,90
Standard silver, unstamped -	144,60	134,80	9,80
Standard silver, stamped -	144,80	134,40	10,40
Fine copper, unstamped -	151,60	144,40	7,20
Fine copper, stamped - -	163,80	154,20	9,60

It appears unnecessary to make any observations upon this experiment, as the results of it so nearly correspond with those of the former, in which whiting was employed.

Experiment III.

Two pieces of each kind of gold, &c. were fixed as before; and the horizontal table was covered with filings of gold made standard by copper. The filings were fixed with a solution of

isinglass; and, after several trials, it was found necessary to replace the weights, which had been removed when the preceding experiment was made, each separate weight being equal to 3 lbs. 8 oz. 12 dts. and 21 grs.

Table X.

Number of revolutions, 660.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Gold 23 car. $3\frac{3}{4}$ grs. unstamped	288	278,30	9,70
Gold 23 car. $3\frac{3}{4}$ grs. stamped	290,20	276,40	13,80
Gold made standard by silver, unstamped - -	268,80	265,70	3,10
Gold made standard by silver, stamped - - -	270,20	264,90	5,30
Gold made standard by silver and copper, unstamped -	278,90	278,80	0,10
Gold made standard by silver and copper, stamped -	281,70	281,30	0,40
Gold made standard by fine copper, unstamped -	239,80	239,20	0,60
Gold made standard by fine copper, stamped - -	261,60	261,20	0,40
Gold made standard by equal parts of fine and dollar copper, unstamped - -	247,70	247,30	0,40
Gold made standard by equal parts of fine and dollar copper, stamped - -	246,40	245,90	0,50
Gold of 18 carats, unstamped	208,80	208.70	0,10
Gold of 18 carats, stamped -	207,90	207,70	0,20

TABLE X. *(continued.)*

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Standard silver, unstamped -	144,80	144	0,80
Standard silver, stamped -	147	146,20	0,80
Fine copper, unstamped -	164	164	—
Fine copper, stamped -	146,60	146,40	0,20

It would be superfluous to make any remarks upon this experiment, as the general results of it agree with those made with the same apparatus, which have been lately described.

Mr. CAVENDISH observes, that if those cases in Table III. are selected, in which one of the pieces rubbed was gold made standard by copper, then, the effect will be discerned which was produced by the friction of different kinds of gold against that metal in a solid form: and again, in Table X. may be seen the effect which was produced by the friction of different kinds of gold, &c. against the same metal, in the form of filings.

TABLE XI.

Quality of the metal.	Table III. Loss per piece.	Table X. Loss per piece.
Fine gold - - - -	0,50	4,85
Gold with silver - - -	0,10	1,55
——— silver and copper -	—	0,05
——— copper - - -	0,05	0,30
Gold of 18 carats - - -	—	0,05
Standard silver - - -	8,20	0,40
Copper - - - - -	43,30	—

The whole motion of the pieces of coin, in the experiment of Table III. was about 687000 inches; while the whole motion of the pieces in the experiment of Table X. was only 62205. The weight by which the pieces were pressed was the same in both experiments, so that the pieces sustained eleven times more friction in the former than in the latter experiment. But it is worthy of notice, that the greater part of the different metals suffered the most considerable diminution by the last mode of examination; and this may be regarded as an additional instance of the small diminution which metal suffers by being rubbed against metal in a solid form, considered comparatively with that which it suffers when rubbed against the same metal in small particles.

Moreover, it is remarkable, that although the diminution of all the metals which have been examined, excepting silver and copper, is less in the IIId than in the Xth Table, yet that of copper is many times greater.

Mr. Cavendish, considering how necessary it was to determine whether there is any material difference, in point of wear, between gold coin intirely of the same quality and that in which the gold is of different qualities, was induced to make the following Table of comparison, formed upon the results stated in Table V.

TABLE XII.

Quality of the metal.		Unstamped pieces. Loss per piece.				Stamped pieces. Loss per piece.			
		1st metal.	2d metal.	Opposed.	Mean.	1st metal.	2d metal.	Opposed.	Mean.
1.	2.	A.	B.	C.	D.	A.	B.	C.	D.
Fine gold - -	Gold and silver	3,15	,05	—	—	,65	,45	1st metal. 1,70	1,55
Fine gold -	Gold and copper	3,15	,05	1st metal. ,50	,05	,65	,15	1st metal. 3,20	,30
Gold and silver	Gold and copper	,05	,05	,10	,10	,45	,15	1st metal. ,60	,45
Gold, silver, and copper - -	Gold, iron, and copper -	uncer.	15,60	2d metal. ,10	,05	,55	2,60	2d metal. 1,60	1,55
Gold and copper -	Gold, iron, and copper -	,05	15,60	2d metal. 7,10	5,20	,15	2,60	1st metal. 2,50	1,95
Gold and silver - -	Gold, silver, and copper -	,05	uncer.	—	—	,45	,55	2d metal. 1,60	1,50
Gold, silver, and copper -	Gold and copper -	uncer.	,05	2d metal. ,10	—	,55	,15	—	—

The two first columns of this Table show the quality of the two metals compared. The columns A B show the loss which each of these metals suffered, when rubbed against metal of the same kind; and the two next columns show their diminution, when rubbed against each other; the column C showing which metal wore the most, together with its diminution, and the column D showing the mean between the diminutions of the two metals. For example, in the first row of the Table, the two metals compared are fine gold and gold alloyed with silver; and, when stamped pieces were employed, the diminution caused by rubbing the first metal against metal of the same kind was 0,65, and the loss of the second metal, by the same treatment, was 0,45; but, when the two metals were rubbed against each other, the first metal was most diminished, and its loss was 1,70; therefore, as the second metal lost 1,40, the mean loss was 1,55.

To judge from the unstamped pieces, it should seem as if a variation in the quality of the gold tended rather to diminish the wear; but, from the effects of the stamped pieces, which are more to be regarded, it seems otherwise. Upon the whole, however, it does not appear to be a matter of much consequence, that the coin should consist intirely of gold of exactly the same quality.

In the following experiment, filings of iron were employed, and were fixed upon the horizontal table by a solution of isinglass. The leaden weights, and the general arrangement, remained as before.

Experiment IV.

TABLE XIII.

Number of revolutions, 404.

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Gold 23 car. $3\frac{3}{4}$ grs. unstamped	276,40	251,40	25
Gold 23 car. $3\frac{3}{4}$ grs. stamped	278,30	251,10	27,20
Gold made standard by silver, unstamped - -	264,90	244,90	20
Gold made standard by silver, stamped - -	265,70	239,40	26,30
Gold made standard by silver and copper, unstamped -	281,30	258,50	22,80
Gold made standard by silver and copper, stamped -	278,80	252,70	26,10
Gold made standard by fine copper, unstamped -	261,20	240,90	20,30
Gold made standard by fine copper, stamped - -	239,20	212,30	26,90

TABLE XIII. *(continued.)*

Quality.	Weight before friction.	Weight after friction.	Loss.
	Grains.	Grains.	Grains.
Gold made standard by equal parts of fine and dollar copper, unstamped - -	245,90	218,10	27,80
Gold made standard by equal parts of fine and dollar copper, stamped - -	247,30	219,90	27,40
Gold of 18 carats, unstamped	207,70	197,50	10,20
Gold of 18 carats, stamped -	208,70	197,80	10,90
Standard silver, unstamped -	146,20	13[illegible],[illegible]0	11,40
Standard silver, stamped -	144	127,60	16,40
Fine copper, unstamped -	146,40	133,80	12,60
Fine copper, stamped -	164	151	13

This experiment proves, that the difference of wear, thus produced upon pieces of gold which do not differ very considerably in comparative ductility, cannot easily be discovered, when the material or method employed to produce abrasion acts with violence and rapidity.

For example, the difference of wear between fine gold and the various kinds of standard gold, appeared more evidently defined, when a soft powder like whiting was employed, and when the abrasion was very slow and gradual, than by the subsequent experiment with sand; but, even in this case, the different and progressive effects became sufficiently apparent. On the contrary, in this last experiment, with the iron filings, very little difference could be perceived, between the wear of fine gold and that of the various kinds of standard gold; for, the rapid and

violent action of the iron filings, resembling that of a rasp, was too powerful to be modified in any very perceptible manner by the different ductility of these pieces; and, consequently, little or no variation in the wear could be observed, excepting in the pieces of gold reduced to 18 carats by copper, which, being hard when compared with the former, were in some measure better able to resist the effects of the filings.

The following comparative Table of the four preceding experiments, will show, by the near agreement of their general results, that the wear of gold, when exposed to the friction of earthy powders, or metallic filings, is in proportion to the relative degree of ductility.

Table XIV.

Comparative Table of the Four preceding Experiments.

	Experiment I.		Experiment II.		Experiment III.		Experiment IV.	
	Revolutions. 11880. Whiting.		Revolutions. 880. Sand.		Revolutions. 660. Filings of Standard gold.		Revolutions. 404. Filings of Iron.	
Quality of the pieces of gold.	Loss.		Loss.		Loss.		Loss.	
	Grains.		Grains.		Grains.		Grains.	
Gold 23 car. $3\frac{3}{4}$ grs. - -	0,80 3,80	4,60	18,10 20,10	38,20	9,70 13,80	23,50	25 27,20	52,20
Gold made standard by silver	0,70 2,70	3,40	16,50 17,60	34,10	3,10 5,30	8,40	20 26,30	46,30
Gold made standard by silver and copper - -	0,30 1,80	2,10	11,60 15	26,60	0,10 0,40	0,50	22,80 26,10	48,90
Gold made standard by fine copper - -	0,70 1,90	2,60	15,50 13,90	29,40	0,60 0,40	1	20,30 26,90	47,20

TABLE XIV. *(continued.)*

	Experiment I.		Experiment II.		Experiment III.		Experiment IV.	
	Revolutions. 11880. Whiting.		Revolutions. 880. Sand.		Revolutions. 660. Filings of Standard gold.		Revolutions, 404. Filings of Iron.	
Quality of the pieces of gold.	Loss.		Loss.		Loss.		Loss.	
	Grains.		Grains.		Grains.		Grains.	
Gold made standard by equal parts of fine and dollar copper	0,20 1,20	1,40	11,90 14,80	26,70	0,40 0,50	0,90	27,80 27,40	55,20
Gold of 18 carats	0,20 0,80	1	9 11,90	20,90	0,10 0,20	0,30	10,20 10,90	21,10
Standard silver	1 0,80	2,80	9,80 10,40	20,20	0,80 0,80	1,60	11,40 16,40	27,80
Fine copper -	0,20 0,20	0,40	7,20 9,60	16,80	— 0,20	0,20	12,60 13	25,60

When the whole of the preceding experiments, made with the three different machines, are viewed and compared, their general results appear to be as follows.

1st. That when equal friction, assisted by a moderate pressure, takes place between pieces of coin which are in each series of a similar quality, then, abrasion is most commonly produced in an inverse ratio to the degree of ductility.

2dly. That the contrary effect happens, when pieces of different qualities rub against each other; for then, the more ductile metal is worn by that which is harder.*

* Some experiments were made at Paris, in 1790, upon pure and upon alloyed silver, the results of which appear to be nearly the same as those of the present experiments upon gold. These experiments upon silver are concisely mentioned as follows. "L'objection la plus forte contre l'usage des metaux purs dans les monnoies, est la crainte "qu'elles ne s'usent plus vite. Mais la dureté que l'alliage leur communique,

3dly. That earthy powders and metallic filings produce similar effects, and tend to wear the different kinds of gold in proportion to their respective degrees of ductility.

Fine gold, being extremely soft and ductile, sustains a considerable loss, under many of the general circumstances of friction; and as at all times it appears certain, that the impressions which have been stamped upon it are most easily obliterated, even when actual abrasion does not take place, there is much reason to conclude, that gold of such extreme ductility is not that which is the most proper to be formed into coin.

But gold of the opposite quality, or at least so hard as to be

"augmente-t'elle ou diminue-t'elle la perte qu'elles essuient par le frottement? C'est "une question qui n'a jamais été résolue par des expériences directes; et l'Academie "se propose d'en faire, pour éclairer un fait dont la connoissance peut être utile, non "seulement pour l'art de fabriquer les monnoies, mais pour un grand nombre d'autres. "*Les premières expériences ont prouvé, que les monnoies d'argent pur perdoient moins* "*que les monnoies alliées, lorsque le frottement avoit lieu entre des pièces semblables,* "*mais qu'elles perdoient davantage, lorsque le frottement avoit lieu entre les pièces* "*pures et les pièces alliées.*"

Rapport fait a l'Academie des Sciences, le 27 Octobre, 1790, sur les titres des Metaux monnoiés, &c. par MM. BORDA, LAGRANGE, LAVOISIER, TILLET, et CONDORCET. *Annales de Chimie*, 1793, Tome XVI. p. 230, et 231.

The effects thus stated to have been produced upon pure and upon alloyed silver, most probably in like manner prevail in respect to gold; but this cannot be stated as a certain fact; for, although there is much reason to suppose, that under a small or very moderate pressure, the wear of gold against gold of an equal quality is uniformly in an inverse ratio to the degree of ductility, and allowing that under such circumstances fine gold would suffer a less diminution than gold which is alloyed, yet the present experiments prove, that under a considerable pressure, the order of wear is in some measure different; for, extremely soft or fine gold is then found to suffer as great, or indeed a greater diminution, than gold which is but moderately ductile: and the whole of the experiments which have been made for the purpose of the present investigation, concur to show, that gold which is neither extremely soft nor extremely hard, is best adapted to resist friction in general.

just capable of being rolled and stamped, seems to be equally improper for the purpose of coin. For, even supposing that hard gold suffered, in every case, less by friction than that which is moderately ductile, (which is not however the fact,) and allowing that standard gold may, by a mixed alloy, be rendered as hard as gold reduced by copper to 18 carats, without changing the standard proportion of gold, yet it would be very difficult always to make such standard gold of an uniform degree of hardness. Moreover, by some experiments which I purposely made at the Mint, upon the rolling and stamping of gold of different qualities, it evidently appeared, that gold equal in hardness to that of 18 carats, could not be employed with advantage; for, the additional labour which was required for the rolling and stamping of this hard gold, the frequent failure in making the impression, and the battering and breaking of the dies, fully proved, that the expense and difficulty attending the working of such gold, would by no means be compensated by any small degree of durability which it might possess over any other.

The extremes of ductility and of hardness being therefore equally objectionable, it follows of course, that gold of moderate ductility must be that which is the best adapted for coin; and, as nothing but silver or copper can be employed to alloy gold which is intended to be coined, it may be here observed, that whatever might have been the original motive for introducing the present standard of 22 carats, yet it appears, from the experiments lately described, that this proportion of $\frac{1}{12}$, of the abovementioned metals, is (every circumstance being considered) the best, or at least as good as any, which could have been chosen.

There is, however, some difference in the quality of gold, when alloyed with the standard proportion of silver, of silver

and copper, and of copper, which requires to be considered.

Gold alloyed with one-twelfth of silver, is of a fine but pale yellow; it is very ductile; it is easily rolled, and may be stamped without being annealed; it consequently does not require to be blanched; and, after the complete process of coining, the surface and every part remains of an uniform quality, so that, by wear, it does not appear of different colours.

These properties are certainly much to be valued; but the objections to this kind of standard gold are,

1st. The additional expense attending the use of silver as an alloy.

2dly. The extreme pale yellow colour. And,

3dly. That, from its great ductility, it is almost as liable to have the impressions which have been made upon it obliterated, as those which have been made upon fine gold.

All things being therefore considered, gold alloyed only with silver, does not appear to be so proper for coin as may at first be imagined.

Gold made standard by a mixture of equal parts of silver and copper, is not so soft as gold alloyed only with silver; neither is it so pale, for it appears to be less removed from the colour of fine gold than either the former or the following metal.

Gold alloyed with silver and copper, when annealed, does not become black, but brown; and this colour is more easily removed by the blanching liquor, or solution of alum, than when the whole of the alloy consists of copper. It may also be rolled and stamped with great facility; and, under many circumstances, it appears to suffer less by friction, than gold alloyed by silver only, or by copper.

But, after it has been subjected to the ordinary friction which must take place during the circulation of money, it is liable to appear of a deeper colour in those parts which are prominent, and are consequently the most exposed to friction. This defect arises from a cause which will soon be explained, but it cannot be regarded as an objection of any weight.

The last kind of standard gold which remains to be mentioned, is that which is alloyed only by copper. This is of a much deeper colour than those which have been hitherto noticed, and it is slightly harder than either of them; but nevertheless it is very ductile, provided that the copper be pure. It requires to be annealed, and then becomes nearly or quite black; which colour is not so easily removed by the blanching liquor, as that which is produced by the process of annealing, upon gold alloyed with a mixture of silver and copper.

It suffers less by many of the varieties of friction, than gold which is alloyed with silver; but, in some cases, it seems to wear rather more than gold alloyed with silver and copper; the difference is not however very considerable.

This sort of standard gold, as well as that which is alloyed with silver and copper, appears commonly, after a certain degree of wear, of a coppery colour, more or less deep, in those parts which are the most prominent; and, when coin thus alloyed exhibits such an appearance, it is frequently and vulgarly said to have been in contact with copper money; and sometimes guineas having this appearance have been refused, upon the supposition that they were debased. But the real fact is, that when copper constitutes part or the whole of the alloy, it becomes oxidized or calcined upon the surface of the blanks, by the process of annealing; and the blackish crust of copper, in

this state, must then be removed by the solution of alum, called the blanching liquor. Now it is evident, that after this operation, the surfaces of the blanks or unstamped pieces, can no longer be regarded as standard gold. For, if copper alone forms the alloy, it must be dissolved and separated from the surface of each piece of coin; and the same effect must also take place, with respect to the copper, in the alloy formed of copper and silver. So that, in the first case, each piece, when blanched, will consist of gold made standard by copper, covered with a thin coat of fine gold; and, in the second case, each piece will be composed of gold made standard by silver and copper, coated with gold alloyed with $\frac{1}{24}$ of silver, or with half of the standard proportion of alloy, supposing the silver and copper to have been in equal quantities. As, therefore, the standard gold of which the pieces consist, is always, more or less, of a deeper colour than the coating or film of the finer gold which covers each piece, it must be evident, that when this coating has been rubbed and removed from the raised or prominent parts, these will appear of a very different and deeper colour than the flat part or ground of the coin. The reason therefore is sufficiently apparent, why gold which is alloyed with silver only, cannot be liable to this blemish.

Upon a comparison of the different qualities of the three kinds of standard gold which have been lately mentioned, it appears, (strictly speaking,) that gold made standard by silver and copper is rather to be preferred for coin; but, as gold made standard by copper alone is not very much inferior in its general properties, it may be questioned, whether the few advantages which are thus gained, will compensate the additional expense of the silver required for half of the alloy; and, indeed,

any extraordinary addition of silver appears to be the less necessary, as there is commonly some silver in the gold which is sent to the Mint, which, being reckoned as part of the alloy, contributes to produce those beneficial effects which result when silver is purposely added.

From a general view of the present experiments, there does not appear to be any very great or remarkable difference in the comparative wear of the three kinds of standard gold, all of which suffer abrasion slowly, and with much difficulty; and (as it has been already observed) the difference of wear between the two last mentioned, is certainly but inconsiderable. For these reasons, and from the consideration of every other circumstance, it must be evident, that the extraordinary loss which the gold coin of this kingdom is stated to have sustained within a certain limited time, cannot, with even a shadow of probability, be attributed to any important defect in the composition or quality of the standard gold; and all that can be said upon this subject is, that some portion of this loss may have been caused by the rough impression and milled edge now in use, by which, each piece of coin acts, and is acted upon by the others, in the manner of a file.

The loss thus occasioned cannot however be considerable; for the quality of the present standard gold is certainly that which is well adapted to resist abrasion, especially in the case of the friction of coin against coin; and this is strongly corroborated by the observations of bankers and others, who are in the habit of sending or receiving large quantities of gold coin from any considerable distance. When a number of guineas, rather loosely packed, have been long shaken together by the motion of a coach or other carriage, the effects of friction are observed

chiefly to fall upon only a few of the pieces. But it is not a little remarkable, that although these are often reduced nearly or quite to the state of plain pieces of metal or blanks, yet, upon being weighed, they are found to have sustained little or no loss; and from this it appears, that the impressions have been obliterated, not by an actual abrasion of the metal, but by the depression of the prominent parts, which have been forced into the mass, and become reduced to a level with the ground of the coin. Pieces of hard gold would not so easily suffer by depression; but the real loss would probably be greater, they being, in the case of the friction of coin against coin of similar quality, more susceptible of abrasion.

Upon the whole, there is every reason to believe, that our gold coin suffers but little by friction against itself; and the chief cause of natural and fair wear probably arises from extraneous and gritty particles, to the action of which the pieces may occasionally be exposed in the course of circulation. But still it must be repeated, that the united effects of every species of friction to which they may be subjected, *fairly and unavoidably*, during circulation, cannot produce any other wear than that which is extremely gradual and slow, and such as will by no means account for the great and rapid diminution which has been observed in the gold coin of this country.

As the general results of each part of this inquiry have been noticed at the close of the different sections, a regular recapitulation would be superfluous. We may however observe, that the experiments on the various alloys of standard gold, concur with established practice and opinion to prove, that only two of the metals, *viz.* silver and copper, are proper to be employed in

the reduction of fine gold to standard for the purpose of coin; but, at the same time, it must be allowed, that the phenomena exhibited by arsenic, antimony, zinc, cobalt, nickel, manganese, bismuth, lead, tin, iron, and platina, are in many respects remarkable, and demonstrate the utility of a regular experimental investigation of metallic alloys.

The contents of the second section show, that numerous causes influence the specific gravity of metals; and, amongst these, it has been long ago observed, that some metals, when added to others, generally produce contraction in the bulk of the mass, or an increase of specific gravity, but that other metals produce effects which are precisely the reverse. This, to a certain extent, is unquestionably true; but it does not follow that each metal which produces contraction or expansion, when added to others, should (as some have supposed) constantly produce similar effects, corresponding to the relative proportion of that particular metal; for we well know that some metals, in like manner, promote the fusibility of others in a much greater degree than could be expected from their natural or inherent fusible property; but then, the maximum of this effect is produced by certain proportions of the different metals, and suffers diminution by any variation in these proportions. It appears, therefore, that this great degree of fusibility, is a property peculiar to the compound, which cannot immediately be attributed to either of the component metals; and I am much deceived, if those alterations in specific gravity which, in like manner, are observed in the various metallic compounds, will not admit of a similar explanation; for, in respect to the contraction or expansion which takes place in consequence of combination, we may believe, that there is a maximum of this contraction or

expansion, dependent on a certain relative proportion of the different metals.

The experiments on the comparative wear of gold, which are described in the last section, were attended with considerable difficulties; for this reason, the conclusions have been founded only upon such facts as were uniformly the same under every circumstance. These general conclusions have been already fully stated; but we may again observe, that gold of moderate ductility is (all things being considered) the best adapted to the purpose of coin, and that the real wear of such coin is, in all probability, very slowly effected; so that a long period of time must elapse, before any considerable diminution in weight can be perceived.

The experiments contained in these three sections were limited to standard gold; and, allowing that some curious and instructive facts have been discovered, still more might have been expected from an extension of such experiments to gold variously alloyed in every possible proportion. But an immense addition to metallurgical science would, in all probability, be derived from a comparative investigation of the whole of the known metallic substances, formed into binary, ternary, and such like combinations, proceeding from the most simple to the most complicated, and accompanied by accurate observations on the lustre, colour, ductility, hardness, specific gravity, and fusibility of the compounds.

Our actual knowledge of the properties of metallic mixtures is certainly very imperfect, and has by no means kept pace with the rapid progress of modern chemistry. Few additions have been made to the compound metals employed by the ancients.

The various mixtures of gold and silver, called electrum,* those of the Corinthian metal,† the varieties of bronze,‡ the compound of copper and zinc now called brass,§ the metal for specula,|| the metal called argentarium,¶ (in some measure answering to our pewter,) the art of plating and of tinning,** and the process of amalgamation,†† evince how great a progress had been made by the ancients in the mixing and working of metals.

Much, however, remains to be done, and much may be expected, from a regular and systematical series of experiments on the properties of compound metals. For, exclusively of the immediate application of many of the alloys to economical purposes, it cannot be doubted that science will derive other considerable advantages; our ideas concerning the properties of the metals, whether simple or mixed, will be much enlarged, and clouds of errors, with the traditionary prejudices which as yet shade this branch of human knowledge, will be dispersed.

* PLINIUS, lib. XXXIII. cap. iv.

† PLIN. lib. XXIV. cap. ii.

‡ Ibid. and cap. ix.

§ PLIN. lib. XXXIV. cap. x.

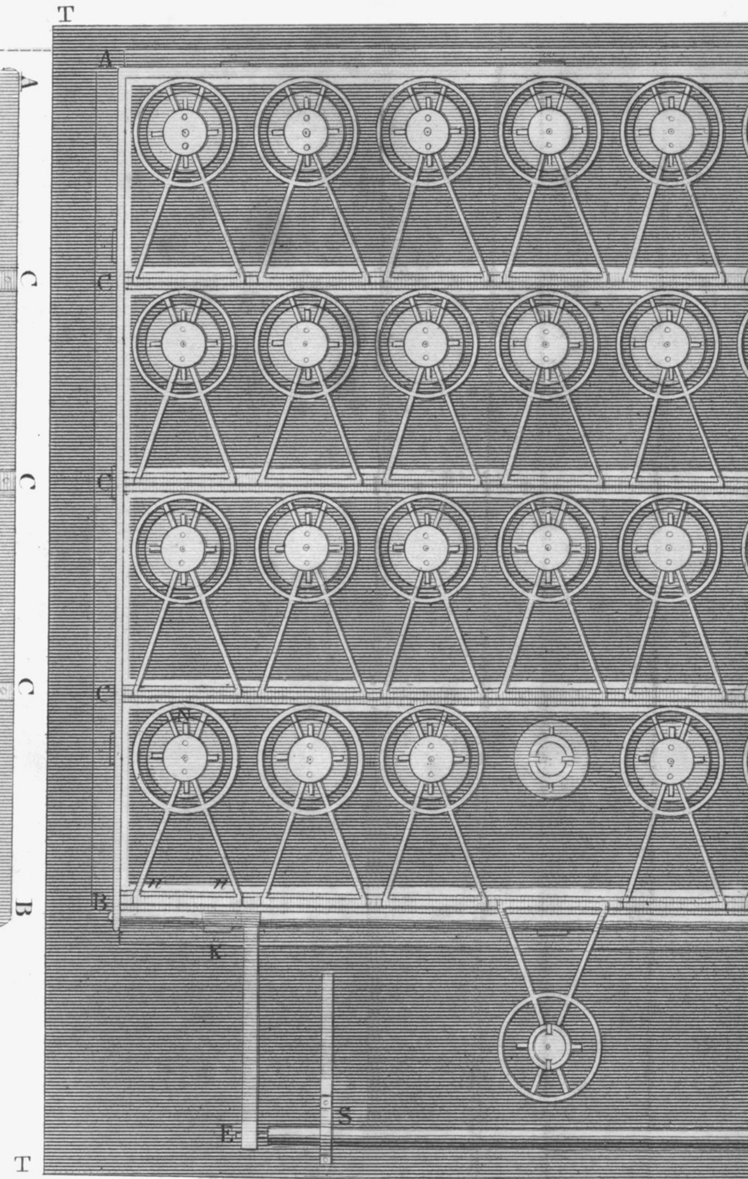
|| PLIN. lib. XXXIII. cap. ix. and lib. XXXIV. cap. xvii.

¶ Ibid.

** Ibid.

†† VITRUVIUS, lib. VII. cap. viii.

Fig. 1.



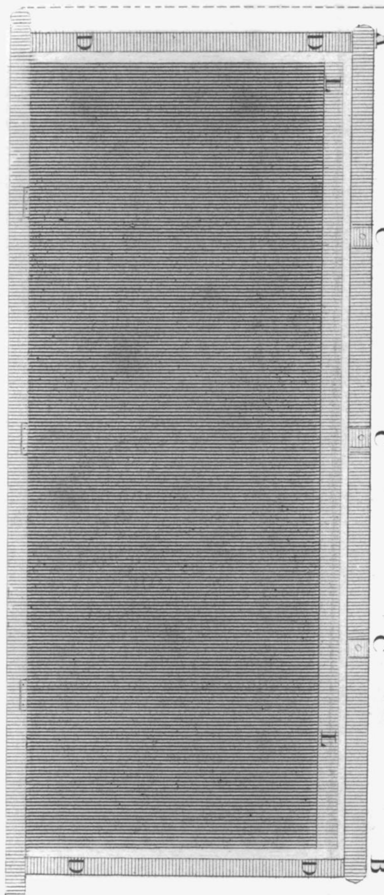
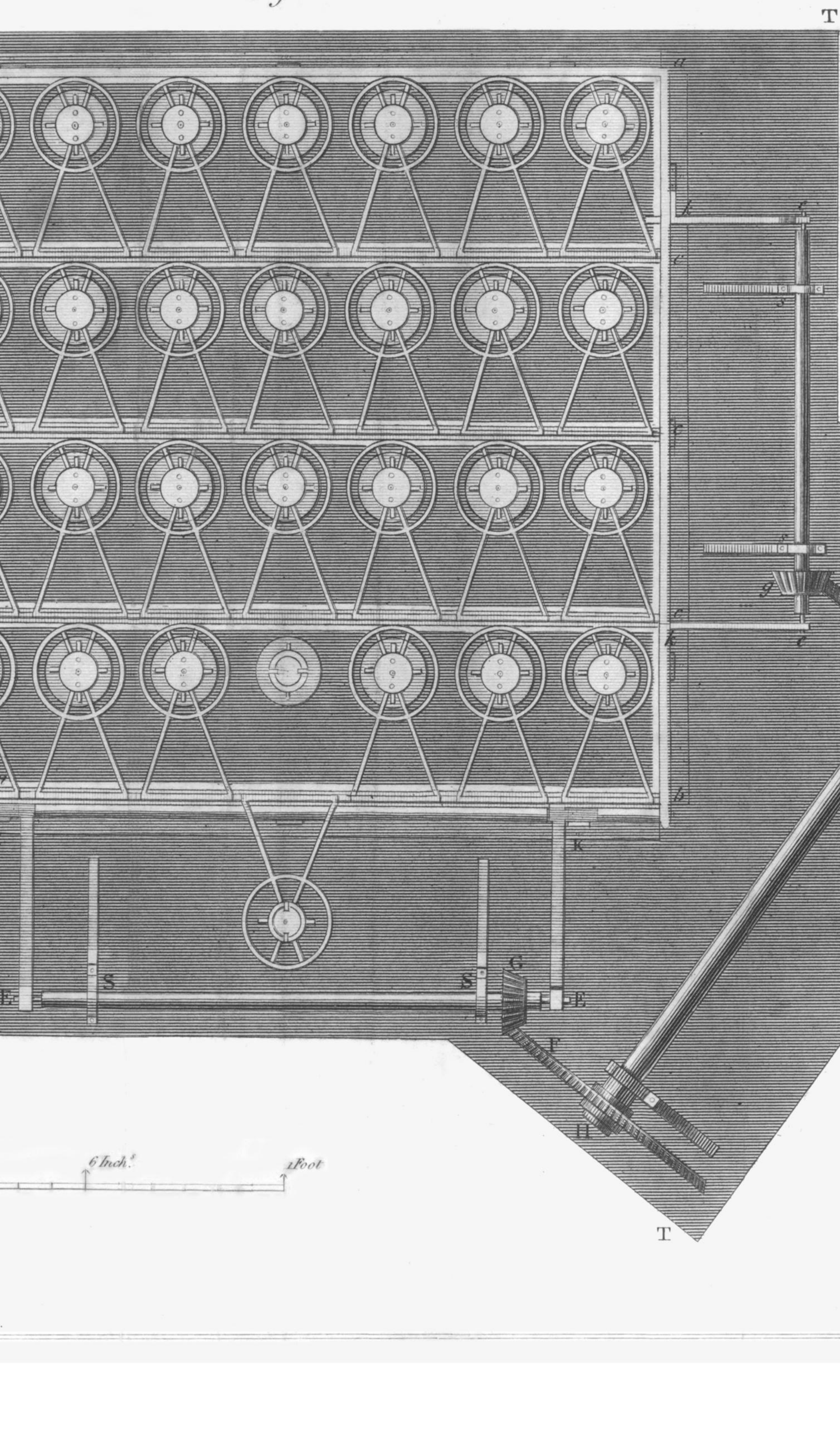
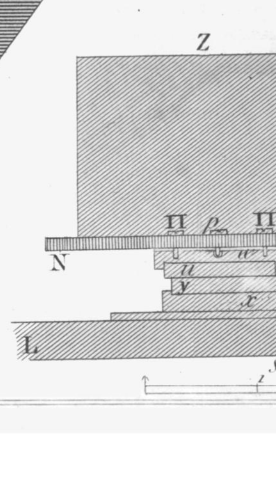


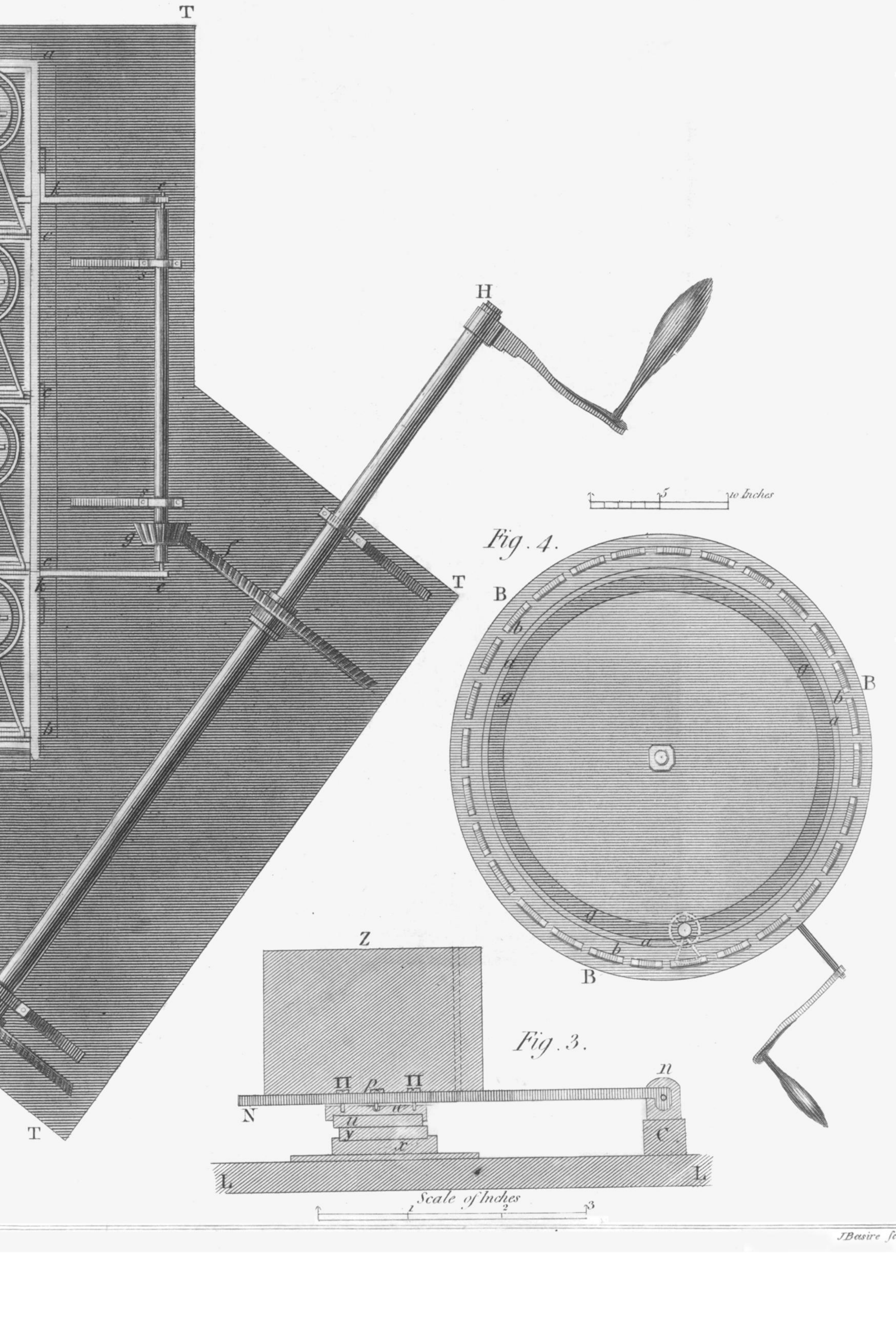
Fig. 2.

Scale — 6 Inch.s — 1 Foot

Fig. 1.







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